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THE

PHYSICS OF THE EARTH.

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FAMILIAR LETTERS

ON THE

PHYSICS OF THE EARTH;

TREATING OF

THE CHIEF MOVEMENTS

OF

The Land, the Waters, and the Air,

AND THE FORCES THAT GIVE RISE TO THEM.

BY HENRY BUFF,

PROFESSOR OF PHYSICS IN THE UNIVERSITY OF GIESSEN.

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TO

NEIL ARNOTT, M.D., F.R.S.

BY WHOM

THE ELEMENTS OF PHYSICS WERE MADE FAMILIAR TO

ENGLISH READERS,

THE TRANSLATION OF THESE LETTERS

IS DEDICATED,

BY HIS ATTACHED FRIEND,

THE EDITOR.

EDITOR'S PREFACE.

In offering the present volume to the British Public, I have but little to add to the statements of the Author concerning the object which he had in writing it.

The rapid progress which science has made during late years, under the united exertions of the naturalists of all countries, has revealed to us many new and remarkable facts relating to the formation and temperature of the Globe, and to the movements of the Ocean and of the Atmosphere, as well as to the influence of both on climate, and on the adaptation of the Earth for the dwelling of man. The deep interest taken in such inquiries has created a great and general demand for information on these subjects, especially with persons who,—unable, from want of time or of the necessary preparation, to enter into the study of the actual phenomena,—must necessarily be satisfied with receiving the results obtained by others. To the desire to supply this want, which is strikingly illustrated by the almost simultaneous publication of several Treatises on similar subjects, these Letters on the Physics of the Earth owe their origin. In their publication, it was not so much the Author's object to offer new facts to the man of science, as to render to a large circle of readers some assistance towards obtaining clearer views and more precise notions of the processes which are at work, on the largest scale, on this our Earth, of the causes by which they are governed, and of their influences on the condition and general features of the surface of the Globe. His Letters are addressed to a person not supposed to have any greater amount of scientific knowledge than is possessed by every man of education:—in language intelligible to such a reader, he endeavours to explain the great phenomena of nature.

How far the Author has succeeded in the task he proposed to himself, I must leave to the decision of the reader; but I may be allowed to state that I was induced to undertake an English edition of these Letters—the contents of which are not immediately connected with my special pursuits—by no other motive than the desire of rendering accessible to the Public a source of information from which I had myself derived no less of profit than of pleasure.

In conclusion, I have to express my sincere thanks to my friend, Mr. C. B. Mansfield, for his valuable assistance in editing the present volume.

A. W. H.

London,
October 26, 1851.

CONTENTS.

LETTER I.

Page

GRAVITY AND ITS EFFECTS 1

LETTER II.

THE TIDES 16

LETTER III.

THE HEAT WITHIN THE EARTH 33

LETTER IV.

WARM SPRINGS 44

LETTER V.

HOT SPRINGS AND JETS OF STEAM 59

LETTER VI.

Page
JETS OF GAS, AND MUD-VOLCANOES 74

LETTER VII.

VOLCANOES AND EARTHQUAKES 87

LETTER VIII.

THE TEMPERATURE OF THE OUTERMOST CRUST OF THE EARTH 115

LETTER IX.

THE TEMPERATURE OF THE LOWEST STRATUM OF THE ATMOSPHERE 132

LETTER X.

THE TEMPERATURE OF THE HIGHER LAYERS OF THE AIR 148

LETTER XI.

THE TEMPERATURE OF THE WATERS, AND THEIR INFLUENCE ON CLIMATE 168

LETTER XII.

THE CURRENTS OF THE SEA 194

LETTER XIII.

Page

THE WINDS 210

LETTER XIV.

THE WINDS, CONTINUED; THEIR INFLUENCE ON CLIMATE 227

LETTER XV.

THE MOISTURE OF THE AIR, AND THE FALL OF WET 241

LETTER XVI.

THE ELECTRICITY OF THE AIR, AND LIGHTNING ... 263

LETTERS
ON THE
PHYSICS OF THE EARTH.

LETTER I.

GRAVITY, AND ITS EFFECTS.

THE ever-varying conditions of the earth and of its surrounding atmosphere, the great changes, which in the lapse of ages have passed over its surface, and the mysterious forces, which are at work within it, have occupied at all times the thoughts of our race; giving rise, as they do, to numberless striking phenomena, and exerting a direct influence upon our physical welfare. Hence at all times thinking men have endeavoured to obtain an insight into the laws which rule the Life of our Planet. It is now no longer doubtful, that the primæval shocks and revolutions, through which the earth has evidently passed, and to which it owes its present form and state, were manifestations of the same natural forces, whose action, sometimes formative, sometimes destructive, we continue to witness at the present day.

Two of these powers, which work throughout the entire universe, and bring under each other's influence all the heavenly bodies—*Gravity* and *Heat*—stand out as the mainsprings both of the past revolutions, and of the present changes of the earth.

Gravity is the principle of attraction and solidity; Heat of expansion and mobility. All material things bear within them these two sources of action. On the one hand, Science points to gravity as an attractive force, put forth by all bodies alike—a force acting with a strength which, for any given distance, is always the same, but which is lessened as the distance is increased. On the other hand, it reveals to us heat as a principle subtle in the extreme, which penetrates the substance of all bodies more or less easily, and accumulates in them to a greater or less amount; it issues again from these bodies, when it does escape, in rays, that is, in straight lines, diverging from each other in all directions. The intensity of the heat-rays also is lessened as the distance from their source is increased, according to the same law as that which governs gravity.

General Gravity (gravitation)—the mutual attracting power of all heavenly bodies—links the earth with its companion, the moon, and leads the latter in its path round the former, and both in their yearly course around the sun. It maintains the equilibrium of our own solar system, and also that of the whole universe.

Earthly Gravity—the mutual attracting power of the atoms of the earth—tends to arrange them about a common central point. If the earth be supposed to be at rest, and covered with water, the attractions exerted upon any one particle near the surface by all the other particles, must together make up one compound force, acting perpendicularly to the motionless surface; for with any other direction of the force, the liquid would yield to it and flow over the surface, which would thus cease to be motionless. The sum of the attractions of all the other particles for any single particle, or for any body upon the earth, is what is called the *weight* of that particle or body. You will thus see why the direction of the pressure, which a body exerts by its weight, must of necessity be perpendicular to the surface of still water, quite independently of the general form of the earth. This form, however, can be no other than a sphere, supposing for the present that the earth is covered with water, and at rest; for it is the only form in which all the parts of the surface keep a like position with regard to each other, and therefore suffer an equally strong attraction. Hence it is the only form in which a state of rest is possible for the surface, the earth itself not being in motion.

The earth, however, is not at rest; it turns round once every day on its axis; so that every point on its surface travels round a circle. The circumferences of these circles answer to the parallels of latitude of the globe. Their diameters are not equal, but increase from the poles to the equator, where their length is greatest. Now you are aware, that any body whirling in a circle, like a weight hung by a string, is always trying to fly from the centre round which it moves, and does actually fly from it, if not kept back by a sufficient power. This tendency is called the "*centrifugal force.*" Its strength increases, as may be ascertained at once by the simplest experiment, in proportion to the mass of the whirling body, and to the quickness of its motion.

If two bodies of equal weight accomplish their revolutions in equal times, as is the case with all bodies on the earth, that one gains the greatest centrifugal force which travels in the greatest circle.

Now, by reason of the daily rolling of the earth round its axis, every particle of it must also get this centrifugal tendency. This is greatest at the equator, and, diminishing as the latitude increases, vanishes at the poles.

Under the equator, the centrifugal force is directly opposed to that of gravity, which is however far greater than the former; otherwise the bodies would be thrown off from the earth. It has been calculated, that if the earth turned round seventeen times as quickly as it does, the centrifugal force at the equator would become exactly equal to the force of gravity. Bodies, in that part of the earth would then seem to have no weight; and anything that might be thrown up to a height, would not return to the earth, but would travel round it, like the moon.

In fact, the moon is in the condition of a body whose centrifugal force is just balanced by its weight. Since the distance of the moon from the earth is known, the strength of the attraction between the two planets is easily calculated. It is found to be three thousand six hundred times less than the force of gravity at the surface of the earth. The centrifugal force of the moon, due to its revolving round the earth, is just equal to this; so that the one of these forces always balances the other, and thus the moon is hindered from ever straying from its path around the earth. The earth and the other planets are in exactly the same condition as regards the sun.

Since the centrifugal force of bodies on the earth acts perpendicularly to the earth's axis, this force cannot act in the direction of gravitation anywhere except at the equator.

For this reason the particles of water north and south of the equator are subject to a force or pressure, whose direction, for any given point, is that of the resultant of the centrifugal and gravitating forces at that point. But since, in order that the water may be at rest, it is necessary that this direction should be perpendicular to the liquid surface of the earth, it follows that the form of this surface cannot be that of a true sphere. Moreover, since the centrifugal force, which, at the equator, is greatest, has there also its whole effect directly opposed to gravity; and since, on the other hand, it not only gradually lessens in power as the latitude increases, but is also less and less directly opposed to gravity, it follows from this, that the downward pressure of bodies at the surface of the earth is least at the equator, and increases towards the poles. The same result must therefore ensue as you may see happen to a blown-up bladder, or to a ball of india-rubber, when more strongly pressed on two opposite sides than on any other part,—it must become flattened towards the points of greatest pressure.

On these grounds, NEWTON had conjectured that the liquid part of the surface of our earth was not quite, but only nearly, spherical; and that, towards the poles, it must be somewhat pressed together; and this long before his reasoning could be confirmed by actual measurement. We now know, from the mean result of numerous measurements, that the flattening amounts to $\frac{1}{300}$, or that the half of the earth's axis is 69,275 feet shorter than the half diameter of the equator, of which the length is 20,922,668 feet.

It is true that the solid part of the earth's surface does not exactly take the curvature of the sea-level, but is in general uneven and sloping. The loftiest mountains, however, do not reach much beyond twenty-eight thousand feet above the sea, a height far less than the amount of flattening at the poles. Besides, most of these lie in the lower latitudes, that is, nearer to the equator than to the poles; while hitherto, only very little land, and that for the most part very low, has been found within the polar circles. The curvature then of the main land is the same in general, if we do not consider its partial unevennesses, as that of the sea; and, therefore, the form of the whole earth is that of a sphere somewhat flattened at the poles.

The deviation of particular parts of the land from this form, or the amount of slope at any place, is readily discovered from the angle which the slanting surface makes with that of still water; for water must, as I have above explained to you, always set horizontally, that is, so that the direction of the earth's attraction (or, rather, of that attraction as changed by the centrifugal force) shall be at right angles (perpendicularly) to its surface.

Again, the direction of rest taken by a string to which a weight is hung (the *Plumb-line*), shows the position of the horizontal plane; for this direction can be no other than that of gravity: because, so long as the string does not lie in the line of this force, the weight attached to it, which is so very easily moved, cannot come to rest.

Heavy bodies, free to move, fall in the direction of the plumb-line; that is, their line of motion is perpendicular to the horizontal surface of the earth. They fall the more quickly, the greater the power which draws them down. They fall least quickly at the equator, more so as the latitude increases, and most quickly at the poles.

The increase, from the equator to the poles, of the speed of fall cannot be learned by the immediate observation of bodies freely falling, since this motion is everywhere too swift to allow of truly measuring the spaces fallen through in given times. However, we can make our observations with the greatest certainty and accuracy, by means of the *Pendulum*, or swinging plumb-line; for it is nothing but the force of gravity that makes the pendulum fulfil its swings, or beats. It begins to move, and goes on swinging, because it has been removed from the position in which the cord hangs straight, and in which alone it can remain at rest. Since gravity is the cause of the beats of the pendulum, these must be faster or slower, or the time of each swing must be shorter or longer, as the power of gravity increases or decreases. The beats of a given pendulum, whose length remains unchanged, mark, as you know, equal lengths of time, which may be measured with surprising accuracy. The slightest changes, therefore, of the power which causes them, may be discovered by the alteration of the time of the swing.

Let then such an instrument—for instance, one that beats seconds, and which is so made as to set right the changes wrought in it by the rise and fall of temperature (called a *compensating* pendulum)—be put up at any place. It will, whenever and however often the time of its swing may be ascertained by a chronometer, always beat seconds. From this constancy of the swing-time at any given place, we must conclude that the force which causes these motions is equally unchangeable.

However, every change of place alters the swing-time of a given pendulum. Placed on a high mountain its beats are perceptibly slower, and they are quicker the nearer it is taken to the poles. The increase, therefore, of the swing-time on rising to a height, and its decrease by removal, on the level, from the equator to the poles, give us a sure proof of the decrease of gravitation as the distance from the centre of the earth increases, as well as of the flattening of the earth at the poles.

By means of the swing-time of the pendulum, we certainly discover, in the first instance, only the strength of the earth's attraction at different points of the surface. But it is clear that, from the proportion which the decrease of this force bears to the increase of the upright height, the law must come out, according to which gravitation lessens as the distance of the points which attract each other becomes greater. And this law being once known, the distance of any point on the surface from the centre of the earth may be at once found, by reckoning from the strength of gravitation as observed at that point. This problem being solved, due regard being had to the effect of the centrifugal force, the amount of flattening is found. The curvature, as discovered by this means, agrees very closely with that found by direct measurements of arcs of the meridian, a process, to treat of which would be to enter the domain of astronomy.

I must not leave the subject of the pendulum, without reminding you that pendulums, differing in bulk and in material, swing in equal times, if their length is exactly the same; that is, they are equally subject to the force of gravitation.

Thus, then, the same plumb-line, which in common life we employ to find a horizontal level, or the true upright line for the walls of a house, and which, swinging as the pendulum, rules the going-rate of our clocks, becomes in the hands of the physical philosopher a most precious instrument.

By this same simple means, he settles by actual trial, and measures (what had been foreseen by theory) the deviation of the form of the earth from that of a sphere; and by its aid he values, both as to kind and as to amount, the attractive power that governs the particles of earth, and binds them together as a whole, which no force from without can sunder.

The same cause which gives rise to the swinging of the pendulum, forces every moveable body to strive for such a position as shall place its centre of gravity as low as possible, and as shall ensure as far as possible its remaining in a state of rest. First then we see that water runs down from mountains and sloping land, till it can find a basin which allows of no escape, in which it can take for itself a level surface, that is, one agreeing with the curvature of the earth, and in which it thus can come to rest. The surface of flowing water in brooks and rivers is not level; if it were so, that is, if the direction of the gravitation of the moving particles were perpendicular to the surface, the force that draws them onward would cease, and the motion which they had already would quickly be stopped by the resistance of the river's bed. The slope of the surface of running water, or its *fall*, agrees in general with that of the bed on which it moves, and is therefore usually greater in highlands than in plains. The speed of the stream increases, if the fall becomes greater. Those rivers are therefore the swiftest that have the greatest fall. The latter, however, as I have already said, answers only *in general* to that of the bottom. When the bed is narrowed for a certain distance, so that the water cannot get through with the speed at which it had been flowing, the fall at once increases; that is, the water is heaped up behind the narrow part of the channel, even when the slant of the bottom remains the same. On the other hand, the effect of the little unevennesses in the bed of the river, such as wave-like ridges, and hollows, and even steep slopes, which, when the water is shallow, may cause rapids for short distances, is more and more smoothed down as the level of the water rises. For the greater swiftness with which the stream is now running at the steeper places, must necessarily heap up, as it were, the water in the lower parts of the river, where before the rise it had been running more slowly; and thus, the more the water rises, over the greater length is its fall spread. Besides, the swiftness of a stream does not depend on the fall alone; for, since the water is always being robbed of part of its motion by the resistance of the ground, and since this loss must ever be made good again by the fall, it is clear that any lessening of the resistance of the ground must enhance the speed of the water, just as does any increase of the fall. In shallow rivers, the whole of the water touches the bottom, in its turn, in a shorter time, and thus meets with more stoppage. This cannot happen so much with deep water, because the film that touches the bottom is much smaller in proportion to the bulk of water that is above it. This shows why the water taken across the breadth of a stream, at any given place, runs more slowly in the shallow parts than in the deeper; and why again the rate of flow of brooks and rivers is greater when they are swelled by floods. And now you will see why, when, in very winding rivers, suitable cuttings are made, which shorten the channel, and for equal lengths increase the fall, the level of the water above must be lowered. The same cause, too, which in every case favours the draining of the water from above the cutting, will not fail, in case of sudden floods, to raise the level in the part below for a time; and this can only be prevented by deepening or widening the channel.

The greatest check which the speed of running water meets with is in large basins, such as lakes, through which it has to run, and in which its motion becomes almost nothing. If the size of a lake is very great in comparison with the width of a river that runs through it, any flood of the latter that soon passes off can but slightly raise the level of the former, and therefore cannot much increase the outflow of water from the lake. Large lakes are, therefore, truly governors of the water-level of a river. Thus, the great lakes of Switzerland, all but one of which pour off their waters through the Rhine, gather during the spring a great part of the snow-water from the mountains, and letting it off slowly, usually keep plenty of water in the Rhine till the summer is pretty far advanced.

The stock of water in the mountains would be thus soon drained off, were it not that the heat returns it to the air in the state of vapour, which is then set down again on the high lands as rain and snow. Thus the waters travel in an everlasting round, which it seems must end at last in making smooth every unevenness on the face of the earth.

By the solvent power of water, some parts of the solid surface of the earth are always being made liquid; others, laid open to the combined influences of water and air, are changed in their nature, and, becoming *weathered*, moulder away. Thus the higher parts of the earth are brought, by degrees, into a moveable condition, and are carried down, partly by their own weight, partly by the force of running water, to the valleys, the plains, and the sea. We see this levelling going on everywhere on the solid land. Stones, and masses of rock, get loosened from the hill-sides, and are slowly filling up the hollows. Even the very mountain-peaks, slowly undermined by the trickling water, and robbed of their supports, are tumbling headlong. Every brook, and every river, more or less, according to its speed, is bearing downwards earth and rolling stones, and, where its stream is slackened, is leaving them as a settlement of flood-soil. Where the rivers run but slowly, their bottom is raised; where they swiftly rush along, the sea-bed at their mouth is filled up by degrees. Thus have the Netherlands been won from the sea, step by step, by the burden set down by the Rhine at its journey's end; and thus has Lower Egypt been built up by the rubbish shot by the Nile. And so we see the coasts at the Mississippi's mouth stretched outwards almost year by year, by the huge bulk of earth and tree-trunks flooded down by the mighty river.

LETTER II.

THE TIDES.

It is not without opposing efforts on the part of the other heavenly bodies that the earth maintains its shape: these efforts indeed are ceaseless, and are put forth most powerfully by the moon by reason of its smaller distance, and by the sun by virtue of its enormous mass. It is true that these forces are unable to draw the solid parts of the earth straightway from their places; but they are strong enough to set up some peculiar periodic movements in the readily lifted masses of the air and of the sea. Those of the atmosphere are not easily seen, and are almost masked by other regular and irregular currents. Those of the sea, however, meet our view at once: they consist in an alternate rising and falling of its surface, each recurring regularly twice in every day, and are generally known as the *ebb* and *flow* of the water, or, shortly, as the *Tides*.

On all sea-coasts, where the tides are felt, the waters are found at all times, even when the air is quite calm and clear, to be in restless motion. Great waves are ever rolling in, and breaking on rocky shores into foam and spray. All parts of the coast-wall that can be loosed from their hold, are step by step torn off by their ceaseless attack; and the firmest rocks are slowly worn and ground away by the sea-sand driven in the water. Numbers too of plants and of animals living in the sea, such as shell-fish, with the remains of fishes, are thrown up and left upon the beach.

It is only on flat or gently sloping shores of narrow-mouthed gulfs, running far up into the land, or on coasts where the force of the ocean-swell is broken by sand-banks, or by reefs of rock at some distance from the land, that this violence of the breakers is assuaged, or altogether calmed.

If you have ever been at the sea-side, at a place where the tides are strong, and where the shore slants gently to the water, you must have remarked that every wave, as it comes in, runs several paces upwards on the beach, and, immediately retreating, leaves uncovered again much of the surface which it had just overflowed, perhaps, by many feet, until the next wave arriving plays the same part again. If the tide is rising you will observe that the retiring water does not fall quite to its former level, and that almost every fresh wave rolls a little higher up than did the one before it. The advance is scarcely perceived at first, but step by step it becomes more evident. About three hours after the moment of lowest ebb the rise of the tide is strongest; then again it becomes slower and slower, till, after three hours more, the flood-tide has reached its greatest height, at which it remains a short time without perceptible change. The fall of the tide begins as slowly as the flow, then the water retreats more quickly, and then again more slowly; and once more, after six hours, the ebb has reached its lowest; and there, again, for a short time its level is kept unchanged.

The sea rises and falls in this manner twice in the day, or, more rightly, twice in the time that passes between one epoch of the moon's crossing the meridian and the next, which makes a period of 1·035 day, or twenty-five hours nearly. Thus the time of high water is later and later every day. For instance, if it is high water to-day exactly at noon, the flood will not be full to-morrow till one o'clock in the afternoon, and so on; so that after fourteen days we shall have high water again at noon, and, when the moon has fulfilled one entire journey round the earth, the third noon-day flood comes up; and thus the tides go on.

The higher the sea rises during the flow of the tide, the lower it falls during the following ebb. The difference between the highest and lowest tide-levels is very unequal on different coasts. In the open ocean the rise of the tide is generally but little. Thus at Otaheite the highest tides do not rise more than eleven inches, and at the Sandwich Islands, only two feet and a half;

and this, although, as you will soon see, it is chiefly in the Pacific Ocean that the tides are generated. At St. Helena they do not rise above three feet; at Martinique and Porto Rico not above a foot and a half; and among the West Indies generally not four feet. Where, on the other hand, the tide meets with many hindrances to its advance, such as coasts which stop it, headlands, round which, or straits, through which, it must run, and particularly gulfs which narrow off towards their upper parts, and mouths of rivers which are open to the direct line of its flow,—in such places, the flood may mount to an amazing height above low-water-mark. Thus, it is said, high up in the Bay of Fundy, between Nova Scotia and New Brunswick, the highest tides rise sixty or seventy feet, while at the same time, at the entrance of the bay, they do not reach a height greater than nine feet. On the coasts of Europe, the Bay of St. Malo and the Bristol Channel are especially remarkable for the great rise and fall of the tide. In the first of these it often rises forty and fifty feet. In general we find, on both sides of the English Channel, a rise and fall of about eighteen or twenty feet; while on the coast of Ireland, and on that of France to the south of Brest (both of which are open to the sea), it is usually not more than from four to six feet. On the German coast of the North Sea the difference between the high and low water-levels amounts to twelve feet; but round the neighbouring island of Heligoland, only to six feet. In the Baltic, and in the Black Sea, there is no ebb and flow. At the end, nearest to the ocean, of the Mediterranean there is a rise of a few inches or one foot. There are more considerable tides at the eastern end of this sea, and in the upper part of the Adriatic. At Venice and at Trieste they rise sometimes nearly four feet.

There are many places on the English shores where you may see the effect of these changes shown in striking contrasts of scenery; perhaps at none more beautifully than at Ilfracombe in Devonshire. But at St. Malo, on the French coast, you may witness this wonderful phenomenon even on a grander scale.

At low tide St. Malo itself seems to be surrounded on three sides with wild craggy rocks, which are covered with mussels and sea-weed, and among which start up the lofty walls of the town. The level places between the cliffs are covered with a layer of fine sand firm enough for walking, and formed almost entirely of powdered mussel-shells. Here and there are pools containing water, which its taste, as well as the number of little crabs, mussels, and star-fish which may be found in it, show to be sea-water left behind by the tide. A fringe of sea-weed marks upon the rocks the line which must be reached by the sea, whose roar is now only heard from a distance. And now, but a few hours later, how changed the scene! The town is almost entirely surrounded by the sea, the waves of which are beating round the walls, breaking at their feet, and throwing the spray sometimes to their very top. The only communication with the land is now afforded by a long causeway, which you see at once to be the work of man, and which is no broader than the road which runs along it. On the side of this causeway towards the open sea, the rolling surge is striving against the barrier which meets it, dashing up in breakers thirty or forty feet high, and drenching with spray the wanderer who may tarry on the road. The many cliffs which had been remarked before are now hidden under water, all but a few of the highest points of rocks, which you could have reached on foot before, but which now are islands in the sea. The other side too of the mole is also washed by the sea. But here the fury of the waves is less, for it has been spent upon all the rocks and islets without; and as the flood has here run far up into the land—having had besides, after passing between the cliffs, to find its way around the town—it retains but little of its former force. Here is the harbour of St. Malo, quite dry at low water, and at flood-tide a great lake roomy enough for several thousand vessels, which, however, you will not see within it.

The height to which the tide rises at any given place is not always the same; it changes every day; and, as you well know, this change is connected with the phases of the moon. At the times of the new moon and of the full moon the flood rises higher, and the fall of the ebb is greater than at others: this increase is called the *Spring-tide.* During the first and last quarters of the moon, the ebb and flow are least. For instance, at Brest there are only eight feet of water at the lowest (or *Neap-*) tides, where at the spring-tides there are nineteen. However, the highest tides do not come exactly with the full and new moons, nor the lowest exactly with the quarters, but they always happen somewhat later. At Brest for instance, the highest spring-tides follow about a day and a half after the new moon and full moon. There is always an increase of the spring-tides at the equinoxes. Eclipses of the moon and of the sun are always accompanied by tides much higher than usual. It is also remarked that the tides are stronger or weaker, according as the moon, whose distance from us, as you know, is always changing, comes nearer to, or is removed farther from, the earth.

When storms happen at the same time with the regular equinoctial tides, which are always very high, and when, as is very often the case, the sea is driven by the gale upon the land, we have a still greater rise of the waters—the *storm-tides.* On the coasts of Germany and the Netherlands they sometimes rise to twice the height of the common spring-tides.

The connection between the tides, and the place of the moon and of the sun, was known to the ancients; but it was NEWTON who first threw a clear light on this fact. His theory has since been so fully established, chiefly by the calculations of Laplace, founded on a great number of observations made on the west coast of France, that, except when foreign influences, such as storms, chance to interfere, not only the times, but also the inequalities in height, of the tides which will occur at any place, may be known by calculation beforehand.

The phenomenon of the tide is caused by the mutual attraction of the earth and the moon, and, though in a less degree, of the earth and the sun. Let us first, to simplify the explanation of this, consider one of these agencies by itself, and that on the supposition that the surface of the earth is formed by one entire ocean. The attraction exerted by one heavenly body upon the particles of another, is the less, as you know, the farther the two are apart. For this reason, the moon, during its *apparent* daily journey round the earth, always most strongly attracts those parts of the latter which lie exactly opposite and nearest to itself, and least strongly those that are farthest off. And the difference between nearest and farthest in this case is by no means inconsiderable, for the mean distance of the moon from the earth's centre is only sixty times the length of the radius of the earth; so that the distances from the moon, of the nearest and farthest parts of the earth, are to each other as fifty-nine to sixty-one.

The whirling or centrifugal force due to the *actual* monthly revolution of the moon round the earth acts upon the latter as an outward pull; just as a weight tied to a string, which you whirl round with your hand, is always felt to exert upon the hand a strain in the direction in which it lies at any moment. Now we must not suppose the centre of the earth, to which the moon is tied by gravity, and round which it turns, to be absolutely still. On the contrary, it must be continually yielding to this strain; and the only reason that its slight movements (with regard to the common centre of gravity of the two planets), which are thus produced, do not affect the general motion of the earth, is, that in one complete revolution of the moon they must mutually compensate each other. While it is thus being moved regularly to and fro by the moon, the earth itself is turning once a day round its own axis, and is thereby always bringing fresh parts of its liquid surface into the places nearest to and farthest from its satellite. Those parts of the earth which come nearest to the moon, are more strongly attracted, and are therefore made to move somewhat quicker than those at the mid-distance. The parts at the greatest distance from the moon are less strongly attracted than those in the middle, and must therefore, if they are liquid, remain somewhat behind these others. From this cause the waters at the two opposite sides of the earth in the direction of the straight line between the centres of the earth and moon, are at the same time raised above the level of the proper surface of the earth; and, in the same manner, when they come to the half-way point of mean distance from the moon, both at the same time, sink down again.

The points of strongest and of weakest attraction move with the moon from east to west, and thus in the period of the *apparent* revolution of the moon round the earth, that is, in one of nearly twenty-five hours, they likewise accomplish their journey round the earth. During this time, therefore, there are brought about, at every part of the liquid surface of the earth, two uprisings of the water—two flood-tides—the one at the time the moon passes the meridian above, the other when it crosses that line below, and two ebbs in the intervals. It is clear, too, that this action must be exerted most strongly on the parts of the earth near the equator, because the distance of the moon from the poles and the parts near them is not at all, or but very little, changed during the daily revolution of the earth.

However the greatest rise of the waters, at any place, does not happen at the moment when the moon passes its meridian, but always somewhat later. For although the cause of the rise is certainly strongest at that moment, yet the water requires time to run up, and besides the influence of the moon continues to act for some time longer with scarcely diminished power. Meanwhile other points of the earth's surface, lying farther to the west, come in turn to be nearest to and farthest from the moon, and thus the tide-wave always advances from east to west, the water continually mounting up on its forward or westward side, and falling on the hinder or eastward side.

But you must not suppose from this, that the tide-water actually flows round the whole earth in a little more than a day. The onward rolling of the tide-wave is not a current at all of the water, but a movement only of the wave, on a vast scale indeed, but still of exactly the same kind as that which you can bring about in any vessel of water, by raising up a part of the liquid at any point and then allowing it to fall. Just like such a little wave in a basin does the tide-wave rise and fall, and is (at least in the open sea) affected with only a slight current-motion towards the west; a motion which only acquires strength when the wave is heaped up, as it were, by obstacles to its progress, as happens to it over the shallow parts of the sea, on the coasts, in gulfs, and in the mouths of rivers, &c. If, for instance, the first wave advancing meets in its course with the resistance of the coasts on the two sides of any narrow sea-channel, it is forced to rise, by the pressure of of the following waves, whose motion is not at all retarded, or certainly less so than that of the first wave; and thus an actual current of the water is set up in straits and narrow channels. Hence the periodical currents of the flood and ebb which are met with in all straits, gulfs, and mouths of rivers in which in general this effect of the tide is felt.

The sun too, quite independently of the moon, by its daily *apparent* motion round the earth, brings about a twofold change of tide. Its strength however is not more than half as great as that of the moon-flood, because the far greater distance of the sun from the earth renders the difference of its attractions on different parts of the earth far less than in the case of the moon. Now, after what I have said above on the cause of the tides in general, you will at once understand, that, at the times of new moon and full moon, that is when the moon stands between the sun and the earth, and when the earth is between the sun and the moon, the attractions of these two bodies acting in concert upon the earth, cause the increase of the ebb and flow or the spring-tides. Again, at the time of the first and last quarter of the moon, that is when the places of the sun and moon are a quarter of a circle apart, the moon-flood must happen together with the ebb due to the sun, and conversely; so that by reason of this contest between the two forces, resulting from the contrast of their position, the tides are brought down to their lowest amount.

It is true that when the moon is new, that planet stands between the sun and the earth, but the three bodies do not then always lie in a straight line; neither are they in the same line when the moon is full. But you will see that the sun and moon will aid each other the more powerfully in raising the tides, the more nearly the three bodies approach the condition of lying in a true right line. This happens most perfectly in autumn and in spring at the times of the equinoxes, when the sun and moon are over the equator at the same time. This shows why the strongest spring-tides occur at these seasons.

The formation and progress of the tide-wave, although in general it is connected with the conditions which I have thus explained, is yet subjected to very considerable changes by the peculiar arrangement of the land and sea. The up-drawing of a perfect tide-wave requires that the moon, or the moon and sun together, should stand on the zenith of some point in the sea (that is to say, right over the head of the observer at that point), while for two other points, or at least for one, of the same sea they must be just on the horizon. At such latter point the tide is at the lowest, just when it is at the highest at the former. From this it is evident, that neither the inland seas or lakes, nor small seas in general, can be subject to a tide of their own. Even the Atlantic Ocean is not broad enough for the formation of a powerful tide-wave. The breadth of this ocean near the equator amounts to forty or fifty degrees, or about one-eighth of the circumference of the earth. But the curvature of the earth's surface is far from being great enough to allow of any considerable difference between the distances of our satellite from any different points of this sea. Only the great Pacific Ocean, whose enormous mass of water embraces nearly half the globe, has width enough for this. The Pacific therefore is the sea from which the tides chiefly come forth. The tide-wave once formed, marches on from this ocean, towards the west, according to the same laws which govern the path of any other wave, which may be raised on any surface of water, whether by the wind, by a stone thrown in, or by any other cause. It reaches the Indian

Ocean, partly running round Australia, partly finding its way through the numerous straits of the Indian Archipelago. The Atlantic Ocean, severed almost entirely from the great ocean by the far-stretching continent of America, receives now most of the remaining force of the wave, as, turning the southern point of Africa, it presses onwards to the north, until it is lost in the Arctic Sea. It is to this that we chiefly owe the tides of our European and American coasts.

Now the tide-wave requires time for its development, and therefore, at the place of its origin, is not completed till after the moon has passed the meridian. Moreover in all smaller seas and arms of the sea, in which tides occur, these tides must be due to the progress of the wave derived from the Pacific Ocean; and the obstacles which oppose its advance, and by which it is at last arrested, vary very much according to the form of the coasts, to the width and depth of the sea, and to the number and size of the islands that it meets with. For these reasons the tides, that visit the coasts of Europe, must be retarded, so as to occur considerably later than the cause from which they arise. Thus for instance the tide-wave requires (according to the reckoning of WHEWELL) fourteen or fifteen hours to travel from the southern end of Africa to the coasts of Spain, of France and of Ireland. And then, on account of the increased resistance there, seven more hours are necessary for it to get through the English Channel. The North Sea receives its tides from the two branches of the tide-wave, one of which comes through the Channel, while the other passes round Scotland. The same tide which appears at Brest at noon, reaches Dover and Calais about seven o'clock, and Ostend about eight in the evening. The same tide running round Scotland, arrives at the mouth of the Thames at eight o'clock on the following morning, as well as on the coast of Germany, where it meets and swells the other wave that came up the Channel.

The tide-water, rising in front of a river's mouth, partly pours itself into the river, and partly prevents the escape of its waters to the sea, so that, in great rivers, the flood is felt many miles up the stream, being however more and more retarded the farther it advances; so much so, that it may easily happen, that at the river's mouth the ebb may have already commenced, while higher up the flood may still be rising.

The causes however of these several delays of the tide remain always the same; the tides must therefore ever follow each other in regular and equal periods. Hence the times of their recurrence may be calculated, from the position of the moon, any length of time beforehand. The regular delay of high water at any place, after the moon's passage of its meridian, on the days of new and of full moon, is called the *Establishment of the Port.* The knowledge of this time is very important to the sailor, because from this he can reckon at what hour on that or on any other day he can run into a harbour, where the rise and fall is great, without danger, and with the advantage of the tide. WHEWELL has remarked, in regard to this, that in open channels, such as the British, the flood-stream continues to run for some time (even as much as three hours) after high-water, and that in the same manner the ebb-stream does not cease at the time of low water, but continues for a certain time longer, which varies according to circumstances, lasting in the Channel till the half tide. This arises from the fact, that the water-level in the English Channel has become much raised, during the flow of the tide, above that of the North Sea, and, on the other hand, during the ebb has fallen considerably below it.

LETTER III.

OF THE HEAT WITHIN THE EARTH.

The life-giving heat, which we enjoy on the surface of the earth, we owe chiefly, indeed almost wholly, to the sun. The heat that reaches us from the other heavenly bodies, is, by reason of their vast distance from us, but a small, indeed almost an imperceptible fraction, compared with that which the sun pours upon the earth.

But the earth possesses a store of heat of its own, besides that which it derives from the sun. The mighty changes of its external condition, which the globe has passed through in countless by-gone ages, and is now passing through on a much reduced scale, seem to depend essentially on a ceaseless struggle between gravitation and the heat of the earth.

The notion had already sprung up among the naturalists even of antiquity, that the earth must have been originally in a glowing melted state. This belief, though it was often thrown aside, always forced itself into notice again; and, with the present extent of our knowledge, its truth can scarcely now be doubted. According to this view, the surface of the earth must have passed from its primitive condition into the state in which it now is, through a process of gradual cooling, at least of the outermost crust of the red-hot mass;—a supposition, in fact, which rests upon several grounds, which agree in warranting its assumption.

The fact that the conditions of the earth are still liable to change, favours the conjecture that the globe itself could not have been created, just as we see it now, ready-made, but that it must have arrived by very slow steps at its present state. The assumption of the spherical shape, which is that of perfect equilibrium for solid particles attracting each other, presupposes, as a necessary condition, a great freedom of motion among those particles, that is, of course, a fluid state. This fluidity of our globe, by the very nature of most of its elements, at least so far as we know, can only be brought about by a very high temperature —by a temperature about as high as that which, doubtless, the sun still maintains. Again the flattening towards the poles, which affects, as you are aware, not only the water, but also the dry land, would without this assumption be unaccountable. Without it we must have considered it as most wonderful, that this deviation from perfect roundness should chance to be exactly as great as, on the assumption of original liquidity, it must have been.

Among the rocks, which compose the solid crust of the earth, there are many whose entire structure proves that they once were liquid, and that they solidified after an extremely gradual cooling. Such are the wide-spread masses of granite, syenite, and felspar-porphyry, which form the lowest layers of many mountains; and the trachyte, dolerite, and basalt, so frequently met with in every country in the world, which, as has been established as a fact by the researches of geologists, have come up in the liquid state through other rocks, and have an unmistakeable resemblance to the matter thrown up from many volcanoes that are yet at work. Several of these minerals have even been formed by artificial melting in our chemical laboratories.

Besides we know, from the great number of active volcanoes, that are scattered over every zone of the earth from the farthest south to the highest north, as well as from the numberless hot springs, that a great part of this primæval heat is even now beneath us. It is true that some have endeavoured to account for volcanic eruptions and hot springs by causes at work in certain places only; for instance by the action of the air, and especially of water, on metals that easily burn, such as potassium, sodium, silicium &c., which they have supposed to be stored up in large masses in the bowels of the earth. Some have pointed to the considerable rise of temperature, which is so often engendered by the slow burning of many compounds of sulphur in coal-mines, and to vast fires thus kindled in the earth. Some have even enlisted into their schemes of explanation the great heat which many salts containing no water give out in taking up that liquid. But even if there be room for supposing that, in some special instances, such local sources of heat have any share in producing the effect, yet the distribution of volcanoes, and hot springs over all parts of the earth, their occurrence among the most different rock-formations, and the often unmistakeable connection between burning mountains lying far apart from each other, are evidences of a far more general and more deeply-seated cause of these phenomena.

But the most decisive proof of the existence of a general store of heat within the earth, is this—that at all places on the globe, starting from a certain limit below the surface, the temperature is found to increase as we descend. This fact, which has but recently been discovered, is now established beyond any doubt.

The influence of the heat coming from without does not penetrate very deep into the earth. You are well aware, that in good cellars it does not freeze in the winter, and that in the summer they remain cool. In many parts of the continent the farmers bury their potatoes and turnips, only three or four feet underground, to protect them from the winter frost; and the workmen employed in the mines, find there from year to year a temperature not the least affected by the variations of that at the surface. Cassini remarked, as early as in 1671, that the temperature in the deep cellars under the observatory in Paris was invariable. Towards the end of the last century a thermometer was placed there in a wide vessel filled with sand, at a depth of eighty-six feet; and during fifty years the instrument has shown an unchanged temperature of 11°·7 C. (53°·06 F.) A like constancy in the amount of heat has been found in many other places, though not by observations carried on for so long a time. The part of the earth's crust, that can be reached by the heat coming from without, has therefore for its lower limit a level, beneath which the temperature at any given place is always the same, and above which, on the contrary, the changes of the outer temperature are more and more perceptible the nearer the surface is approached. In the temperate zone the changes due to the heat from without vanish at a depth of about sixty-four feet; at a much less depth in the hotter regions of the earth, and near the equator at a depth of three or four feet.

Below this limit of constant temperature we find, in every part of the world, the heat steadily increasing with the depth.

This remarkable fact, although long known to miners, had not, however, been regularly observed before the middle of the last century. But since that time observations on this head have been carefully made at many places: in Germany especially in the mines of the Erzgebirge, in Switzerland, in France, in England, in Sweden, in Italy, and even in several mines of Mexico and Peru. At several places they were continued for a long time, and at some have been followed up till very lately. The temperature has been found everywhere to increase with the depth. No trustworthy statements have been made tending to disprove the universality of this fact. In the north of Siberia at Yakutsk, where the frozen soil, even in the middle of summer, is thawed only to the depth of three feet, it was found in digging a well that the cold became gradually less, and that at last at a depth of three hundred and eighty feet the ground was soft. I subjoin the numbers obtained in this remarkable experiment, which was begun in 1830, but not finished before 1837.

Depth in feet.	Degrees of Temperature.	
	Centigrade.	Fahrenheit.
0	—9 (Mean of the year.)	15·8
82	—7	19·4
127	—5	23
221	—2·5	27·5
407	—0·6	30·92

Nor less decisive of this question is the fact, that in the borings for deep wells, of which such a surprising number have been carried out of late years, the temperature has always been found to increase gradually as the depth increased. Some of these wells have been sunk to a depth of fifteen and eighteen hundred feet, one at Neusalzwerk, in Westphalia, even to two thousand two hundred feet. In this latter the thermometer rose to 32°·75 C. (90°·95 F.), a height which in this place it never reaches at the surface.

The results of the observations hitherto made in mines, have not yet led us to any certain conclusions as to the law of this gradual increase of temperature. However, from several experiments made, under peculiarly favourable circumstances, in some of these borings, it is quite evident that the *temperature increases in direct proportion to the depth.* Here I may instance two sets of observations, which were made by different inquirers, under very different conditions. The one was made by De la Rive and Marcet, in a mountainous district, at Pregny near Geneva, more than fourteen thousand feet above the sea (the mouth of the boring was two hundred and ninety-nine feet above the Lake); the other by Magnus in a boring (near Rüdersdorf in the Margravate of Brandenburg), which reaches to seven hundred and thirty feet below the sea-level.

	Depth below the surface in feet.	Degrees of Temperature.			
		At each depth.		Differences.	
		Cent.	Fahr.	Cent.	Fahr.
AT PREGNY.	0	9·75 {(Mean of the year.)	49·55	...	...
	30	10·5	50·90	...	...
	60	10·625	51·125	...	...
	100	11	51·80	...	...
		. . . . .	. . . .	0·875	1·575
	200	11·875	53·375		
		. . . . .	. . . .	1·250	2·404
	300	13·125	55·779		
		. . . . .	. . . .	1·087	1·802
	400	14·212	57·581		
		. . . . .	. . . .	1·038	1·869
	500	15·25	59·45		
		. . . . .	. . . .	1·062	1·911
	600	16·312	61·361	...	...
	680	17·250	63·05	...	...
AT RÜDERSDORF.	0	8·5 {(Mean of the year.)	47·30	...	...
	80	10	50	...	...
	200	13·44	56·19	...	...
		. . . . .	. . . .	1·49	2·68
	300	14·93	58·87		
		. . . . .	. . . .	1·43	2·57
	400	16·36	61·44		
		. . . . .	. . . .	1·39	2·51
	500	17·75	63·95		
		. . . . .	. . . .	1·37	2·46
	600	19·12	66·41		
		. . . . .	. . . .	1·61	2·90
	700	20·73	69·31		
		. . . . .	. . . .	1·61	2·90
	800	22·34	72·21	...	...
	880	23·50	74·30	...	...

The experiments made at various places do not agree accurately in their results, as to the depths for which the thermometer rises one degree of the Centrigade scale. You will at once understand that there must be a difference in the results, according as the borings are made in high land, in valleys, or in plains. Besides it must not be supposed that the shell of the earth is everywhere equally conductive of heat; and there may be many cases, especially in the higher parts of the bore-holes, in which it may have been impossible to shut out entirely all atmospheric influences; such for instance as the oozing in of cold surface-water. Lastly there is only one condition in which we can conclude with certainty, that the temperature of the water, with which the shaft is always filled, is that of the ground at the depth which the shaft has reached: this is when this water has remained at the same point for a long time, and cannot be mixed, ever so slightly, during the observation, with the waters rising up from below, or with those coming through from above.

We may assume, taking an average deduced from the best observations, that the temperature rises about one degree of the Centigrade scale (1°·8 Fahr.) for every hundred feet of depth.

But how is it possible, you will ask, to mark the height of a thermometer in the depths of these borings? There are many means of doing this. The simplest is the following: to let down into the shaft a correct thermometer, clothed with some material that conducts heat very slowly, and to leave it there until you are quite sure that it must have taken the temperature of the place. Of the time necessary for this you must have satisfied yourself by previous experiments. The movements of the instrument are so much retarded by the covering, that there can be no change of its indication while you are withdrawing it, and reading off the degree recorded. In fact this method, with careful management, leaves nothing to be desired.

But there are also instruments specially contrived for the purpose of measuring temperature at times and places at which the observer cannot be present. The best known is the *Registering Thermometer*, which shows both the highest and lowest temperature which has occurred during any length of time that may be desired. You will find it described in works on physical science.

The regular increase of the temperature of the ground in proportion to the depth, agrees altogether with the law, which physicists have ascertained to govern the propagation of heat through walls of uniform material, and exposed on their different sides to unvarying but different degrees of heat. We find one of these constant temperatures in the solid earth-crust, at the imaginary surface which limits the influx of heat from without: of the place of the other we know nothing, except that, considering all that we have yet learned on the subject, it must lie far below the greatest depths that have yet been reached by our boring-rods. It may therefore be assumed with all likelihood of truth, that, so far downwards as the condition of the ground remains nearly the same, the rise of temperature with the increase of depth proceeds according to the same law that has been already established for the upper strata.

If the increase of heat is taken to be one degree (Centigrade) for every hundred feet of depth, we should find, at a depth of ten thousand feet, a temperature at which water would boil. At one hundred and twenty thousand feet below the surface, about twenty-three miles, and only $\frac{1}{160}$ of the length of the earth's radius, there must be a heat of 1200° Centrigrade (nearly 2200° Fahr.) at which cast-iron melts and basalt runs like water.

Although we cannot give to these calculations any greater value than that of being somewhere near the truth, yet it is evident enough that the cooled and hardened crust of our earth can form but a small portion of its bulk, and that a vastly greater mass of it must be still perhaps not entirely in a molten liquid state, but at least in one of glowing heat. This belief, which is so well founded, as to be now accepted by all geologists, gives us the key to the explanation of hot springs, of earthquakes, and of volcanoes.

LETTER IV.

ON WARM SPRINGS.

The rocks, of which the outer crust of the earth is made up, are everywhere more or less traversed with clefts and hollows. These interstices form natural basins which become filled with water, and channels are established in which streams are running often to great distances under-ground. When such water-courses reach the surface at spots, which lie below the level of the basin, the water flows forth; and thus *Springs* are formed. However, springs may also be the discharges of reservoirs that lie below them, if these latter receive their supplies from places higher than the level of the springs. In other words, if the columns of liquid in the fissures are connected so as to form a bent tube, filled with water, and having one limb shorter than the other, then the liquid must run out through any opening in the shorter limb: this you may see any day in the pipes of our waterworks. The velocity of the flow depends on the difference of the height of the two limbs of the bent tube, and augments as this difference increases.

It is this property of water which enables us to open springs by sinking wells, or by piercing the earth with the boring rod. If the boring auger breaks into a reservoir of water, the contents of the latter rise up the shaft, and flow out, often gushing up as a fountain, if the reservoir below derives its supplies from higher levels. Such are the *Artesian Springs* or *Spring Wells,* which owe their origin to the very same principles as do artificial fountains. Geology teaches us the circumstances under which we may form conclusions with the greatest probability of truth as to the existence of subterraneous veins of water; and therefore the experiment of boring for water, if conducted by an experienced geologist, cannot be considered as a speculation of mere hazard.

One condition, that is universally requisite for the formation of artesian spring-wells, is, that there should lie at some depth below the surface a stratum having an inclination to the horizon, and traversed with fissures (a feature which belongs especially to the limestone rocks). Another is that this stratum must, at some higher level, crop out to the surface or at least only be covered with some light soil, which allows the water to trickle through: and over its lower parts must lie some stratum through which water cannot pass, as for instance a thick layer of stiff clay; so that the rain water draining in from above may fill the hollows, and may run down the slope of the bed underneath the clay. Now this clay must be pierced before we can reach the water. That this is the origin of spring-wells, as well as of wells in general, may nearly always be most clearly shown by the local features of the case. But sometimes successful borings for springs are made in plains, and at great distances from the slopes of hills. This can only be explained by supposing that there are channels running under-ground, and that often for several miles. This view is sufficiently borne out by the well-known fact, that many small rivers, which disappear in fissured strata, come up again at distant spots. And the existence of subterranean communications, which conduct the water from places lying at high levels to very considerable distances in the plains, is proved in certain cases by indisputable facts.

An Artesian well in the town of Tours on the Loire, which brings up the water to the surface from a depth of three hundred and fifty-five feet, threw up, on the 30th of June, 1831, many pieces of plants and shells, mixed with a quantity of fine sand. There were found, among these, thorn-twigs several inches long, fresh stems and roots of bog-plants, seeds of many plants, especially of one that grows abundantly in marshes; these were in a state of preservation which showed that they had not been lying in water more than three or four months; and lastly there were the shells of fresh-water mussels, and of land snails. All these remains were just like those which are found after floods on the banks of little rivers and brooks. These could not have reached the bottom of the spring-well by oozing through the ground, but only through actual channels open to the air. The same remark applies to one of these wells at Elbœuf near the Seine, from which several small living eels were once thrown up.

The boring tool, in sinking these shafts, sometimes strikes into spacious underground caverns, filled with water; when this occurs the rods, as soon as the resistance ceases, plunge suddenly down often to a depth of twenty or thirty feet. In some instances it has been observed that the water gushed up with such force as to shake the boring-rods in the shaft. It has also happened that when the auger has been drawn up, the water, starting after it, has overflowed all the surrounding place before it could be stopped.

The original purpose of sinking artesian wells was to obtain drinking water, and in several cases brine-springs. The abundance of water yielded by many of these wells, and the fact that their temperature was almost always higher than that of the air, have since found for them many useful applications. At some places in the north of France, the jet, as it escapes from the earth, has been found capable of driving a mill-wheel.

In a factory at Heilbronn five spring-wells, some of which are not one hundred feet deep, and from which the water rises eight feet above the level of the Neckar, yield enough pure water to supply all the wants of two paper-works, of a bleaching, and of a flax-spinning establishment. Moreover, as these springs have a constant temperature of 12°·5 C. (55°·4 Fahr.), the proprietors are enabled by letting the water run from the vessels into the mill-trunk to keep the wheel free from ice during the severest cold of winter. This last application has since been imitated at several other places.

Several artesian wells have obtained a great reputation as medicinal springs; as, for instance, the mineral waters of Cannstadt, which contain salt and carbonic acid, supplied by a well that was bored in 1777. The salt-spring at the baths of Nauheim in the Wetterau comes up out of the bore-hole with a temperature of 30° C. (86° F.) This warm brine-spring broke out not long ago through an old deep boring, that had been abandoned for some years, and has been throwing up ever since without intermission a jet of foaming water from the well's mouth. A still more striking instance of the force with which underground waters flow, was given in the year 1763 at Dürrenberg. A mine-shaft had been sunk to a depth of seven hundred and ninety-one feet, when suddenly it was burst into by the pressure of the water, and the salt-spring rushed in with such force, that in less than two hours it filled to overflowing the well, which was five yards square in section. One of the workmen was caught in the rush of water, and, strange to say, carried up the shaft two hundred and fifty feet without hurt. It is very remarkable that in the Amalienbad at Langenbrücken, a sulphur-spring was found by means of the boring-rod. It rises to eight feet above the ground from a depth of fifty-eight feet, has a temperature of 13°·4 C. (56°·12 F.), and holds no salts in solution.

Brine-springs that now flow over at the surface have often been found by boring. Among the most remarkable are those of Artern on the Unstruth, and of Neusalzwerk near Rehme, not far from Minden. At Artern they found, at a depth of a thousand feet, a bed of rock-salt, from which a saturated solution of salt (containing 27·4 per cent) rises, and runs over at the top with a temperature of 18°·5 C. (65·3 F.) The Neusalzwerk spring is not distinguished by its quantity of salt, for it contains but 4 per cent, but by its extreme abundance of water. In the year 1843 it yielded daily 440,000 gallons of salt water, that is 145,800 pounds of salt, which makes for the year a cube of rock-salt, seventy two feet long in the side. Since then the bore has become considerably deeper, and the water, which now flows from it from a depth of two thousand two hundred and twelve feet, has a temperature of 32°·75 C. (90°·95 F.) The famous well of Grenelle at Paris is still more remarkable for its copious supply of water; it throws up in twenty-four hours 744,490 gallons of water. The water comes from a depth of sixteen hundred and eighty-six feet, and rises through an additonal pipe eighty-six feet more above the surface.

A well, that was bored fifteen years ago at Bruck near Erlangen, affords an instance of the great pressure of such springs. The water gushes out from it with such force, that when a tube four inches in diameter was fixed to the mouth of the well, the water spouted up to a height of thirty-eight feet; and when this pipe was changed for a leather hose two inches wide it even threw its jet seventy feet high.

According to a statement which has been made in the scientific journals, it seems that, in some of the oases of Upper Egypt, the ancient inhabitants of the country used to water their land for the purposes of cultivation by means of bored wells. And, according to the English traveller Wellsted, the people of the province of Oman, on the east coast of Arabia, succeed in giving the richest fertility to some parts of their land, surrounded as it is by sandy deserts; and this they accomplish by watering it from springs which they have opened and conducted underground from distant heights.

Since the ground is a very bad conductor of heat, the water can take but very slowly the temperature of the strata with which it is in contact. The amount of heat, which it has when entering the earth, or which it acquires by its intimate mixture with loose soils, the length and depth of the natural channels through which it finds its way, and lastly the time it has remained in the lower strata, have for this reason considerable influence on the temperature of the springs. From this you will understand at once, that you can draw no sure inference, from the temperature of a spring, as to that of the stratum from which it rises. Thus on the slopes of high mountains, especially of such as are covered with perpetual snow, we very often meet with cold springs which are doubtless in connection with reservoirs at higher levels, to which they owe their low temperature.

On the other hand we must suppose that well-water, rising from water-veins or basins at a great depth underground, will bring up with it a temperature higher than the mean of the soil at the well's mouth; and that its excess above this will be the greater, the greater the depth from which it starts, and the larger the hollows in which it had been collected before its escape.

Since, however, it often happens that a boring cuts through several water-beds one after the other, it is easy to understand the very common case of springs of different temperature rising in the same neighbourhood, and even quite close together.

Springs occur everywhere, which have a constant temperature, that is, one not affected by the changes of the seasons. By far the greatest number of them are warmer than the mean temperature of the soil out of which they rise. These must therefore have got part of their heat from the store within the earth, some more, some less, according to the depth of their source: and all such must come up from depths below the limit of the influence of the external heat. If this were not the case, their temperature must change with the seasons of the year.

The springs named in the following table belong to this class, as appears from a comparison of their temperature with that of the soil at their mouth. They are a few instances chosen from a great number, all of which would serve equally well as proofs, that springs which are warmer than the soil out of which they flow, are to be found of all temperatures within the limits between which water remains liquid.

Name of Place.	Degrees of Temperature			
	Of the Springs (constant).		Of the Soil (mean).	
	Cent.	Fahr.	Cent.	Fahr.
Enontekis (Lapland)	1·1	33·98	− 3·75	26·25
Umca	2·9	37·22	+ 0·75	33·35
Upsala	6·5	43·7	5·56	42·008
Carlscrona.	8·5	47·3	7·9	46·22
Berlin	...	...	8·5	47·3
The Louisenbrunnen	9·6	49·28	...	...
On the Ravensbergen	10·04	50·072	...	...
Frankfort (on Maine).	...	...	9·8	49·64
Schwalheim	12·5	54·5	...	...
Karben.	15	59	...	...
Selters	16·8	62·24	...	...
Sooden.				
The Acid Spring	13·1	55·58	...	...
„ Salt „	20	0·68	...	...
„ Milk „	22·5	72·5	...	...
Nauheim	30	86	...	...
Schlangenbad	31·25	88·25	...	...
Ems	56·25	133·25	...	...
Wiesbaden	70	158	...	...
Burtscheid	77·5	171·5	10	50
Trincheras (near Puerto Cabello)	97	206·6	27	80·6

Though some of these springs may have been called distinctively warm or hot springs, you will see that this name is only to be understood relatively, and as betokening certain effects on our sensations, and by no means as expressing any peculiar properties in the waters. In fact they all owe their warmth to the same cause, and the differences between them, in this respect, depend almost entirely on the depths of their sources.

The fact, that in all parts of the world there are to be found springs, whose high temperature cannot be accounted for by the influence of external heat, justifies, and establishes as universally true, the proposition, from which we started; namely, that the heat of the earth increases with the depth. The hot springs take up for us, as it were, the thread of the proof, which the boring experiments, by reason of their limited depth, had left incomplete.

Spring water usually contains mineral matters in solution. However there are some, even hot springs, which are almost as pure as rain water. Such are the springs at Plombières in Lorraine, with a temperature of 65° C. (149° F.), that at Gastein of 47°·5 C. (117°·5 F.), at Pfeffers of 37°·2 C. (99° F.), at Wildbad (in Würtemberg) of 37°·5 C. (99°·5 F.); at Badenweiler (in the Black Forest) of 27°·5 C. (81°·5 F.) and at Warmbrunn in Silesia of 36° C. (96°·8 F.). The Peters' springs, again, in the Caucasus, having a temperature of 90° C. (194° F.), are almost devoid of solid substances. Other hot springs such as that of Pisa, at 44° C. (111°·2 F.); of Lucca, at 50° C. (122°·9 F.); of Bagnères de Bigorre, at 50° C. (129°·2 F.); of Leuk, at 34°—50°·5 C. (93°·2

—122°·9 F.) hold only a small quantity of sulphate of lime in solution. However most springs rising from deep-seated sources contain solid matter, often a great variety of substances, and some one generally in greatest abundance.

Some persons have entertained most curious notions about the origin of the mineral constituents of springs. The true explanation is, that the water gradually takes up the soluble matters of the strata through which it passes, just as we always see taking place when we put soluble substances into water. Thus the water of by far the greatest number of springs contains some carbonate of lime (limestone), because lime is one of the most widely spread of all the rocks that form the crust of the earth, and is made slightly soluble by the carbonic acid which is almost always present in the water. Springs which rise out of beds that throw off carbonic acid in considerable quantities, take up a proportionally greater amount of carbonic acid, and thereby become carbonated waters. If water comes in contact, within the earth, with rocks containing salt, or perhaps even with a bed of rock-salt, it forms a brine more or less saturated. Just in the same manner sulphate of lime, sulphate of soda, iron, magnesia, and sometimes the carbonates of the alkalies, and compounds of sulphur, even sulphuretted hydrogen, find their way into the spring water. The temperature of the water exerts no influence on the properties of the salts which it dissolves, and comparatively little on the quantity of them, that is taken up. Thus we find carbonic acid in springs of very different temperature, hot as well as cold. The Carlsbad "Sprudel" at 75° C. (167° F.), and the Nauheim spring-well at 30° C. (86° F.) bring up a large quantity of carbonic acid. This gas however can only be kept dissolved in any considerable quantity at the surface of the earth, by *cold* water; so that those that are specially called carbonated springs, are always of a low temperature; as that of Selters, at 16°·8 C. (62°·24 F.); that of Pyrmont, at 13°·75 C. (56°·75F.); of Schwalheim at 12°.5C. (54°·5 F.); Rohitsch at 11°·25 C. (52°·25 F.); Geilnau at 11° C. (51°·8 F.); Fachingen at 10° C. (50°F.); Schwalbach at 10° C. &c. Most carbonated waters contain some carbonate of iron, which, like carbonate of lime, is soluble in water charged with carbonic acid. When the waters have the peculiar taste of iron very strongly, as is the case with the waters of Pyrmont, Langenschwalbach, Rohitsch, Spa, &c., they are called *Chalybeates.*

Among the springs which have a strong taste of the sulphides of the alkali-metals, or of sulphuretted hydrogen — springs which are called sulphur-waters—some are found of a very high, and others of a low temperature. The famous sulphur-springs at Aix-la-Chapelle have a temperature of from

44° to 57°·5 C. (111°·2 to 135°·5 F.); one of the springs at Burtscheid near Aix-la-Chapelle is even as high as 77°·5 C. (171°·5 F.); that of Baden in Aargau is at 64° C. (147°·2 F.); of Aix les Bains in Savoy at 54°·3 C. (130°·74 F.); Mehadia in Hungary, 53° C. (127°·4 F.); Barrèges, 40° C. (104° F.); Baden, near Vienna, 29°·57 C. (83°·75 F.); while the sulphur-bath of Nenndorf is only 10° C. (50° F.), and Bentheim 10° C.

Neither is the quantity of salt contained in springs proportional to their heat. The temperature of several brine-springs, that are nearly saturated, is only a very few degrees above that of the ground, while the famous hot wells of Wiesbaden, at 70° C. (158° F.), and of Baden-Baden, at 67°·5 C. (153°·5 F.), are by no means remarkable for their richness in salt. Common salt too, by reason of its very general distribution over the earth, is one of the most usual constituents of mineral waters. Glauber's salt (sulphate of soda) is more seldom present in great quantity; however it is so in the well-known "Sprudel" of Carlsbad, at 75° C. (167° F.); in the springs of Bath at 46°·25 C. (115°·25 F.); of Lavey, in the Canton of Vaud, at 45° C. (113° F.); of St. Gervais, in Savoy, at 41°·25 C. (106°·25 F.); Marienbad, in Bohemia, 12° C. (53°·6 F.); &c.

Springs that contain alkalies, especially carbonate of soda, as their chief ingredient, are still more rare. Aigues-Chaudes, in the Department of Cantal in France, with a temperature* of 87°·5 C. (189°·5 F.); Vichy, in the Department of Allier, with one of 45° C. (113° F.); the "Kaiserquelle" at Ofen, of 61° C. (141°·8 F.); Töplitz, in Bohemia, of 49°·4 C. (120°·92 F.); Ems, of 56°·25 C. (133°·25 F.); Schlangenbad, of 31°·25 C. (88°·25 F.); Geilnau, of 10°·6 C. (51°·8 F.); Fachingen, of 10° C. (50° F.), are instances of alkaline springs.

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* The hot spring of Aigues-Chaudes yields daily fifty thousand gallons of water. This is conducted in winter through branching pipes into many houses in the town, and serves as a source of warmth. According to the reckoning of Berthier, it supplies the inhabitants with an annual stock of heat equal to that yielded by the fuel of a forest covering 1,335 acres.

LETTER V.

HOT SPRINGS AND JETS OF STEAM.

Besides the effect of water-pressure in siphon-shaped clefts in the earth, which is by far the most general cause of the formation of springs, there is another agency concerned in effects of this kind. This is the expansive force, or pressure, of gaseous bodies, especially of carbonic acid and of steam; this kind of pressure also acts sometimes with enormous power in forcing water to flow within the earth, and to spout up above its surface.

I have already pointed out to you that, at a depth of about ten thousand feet, water must take the boiling temperature by the internal heat of the earth. But it by no means follows from this that water must be there actually boiling. For the process of boiling, that is the rising of bubbles of vapour from within the water, implies (as we learn from physicists) as a necessary condition, that the pressure on the surface of the water must be less, or at any rate not greater, than the counterpressure of the expanding steam. Now it may be considered as generally true, that, however deep the clefts in the earth may be, they must become quite filled with water in a short time. We may therefore assume, that the water, which has found its way down to the depth I have mentioned, has to bear the load of a column of water ten thousand feet high, that is to say a pressure of $\frac{10000}{34}$ or about two hundred and ninety-four atmospheres (taking the pressure of the atmosphere as equal to that of a water-column thirty-four feet in height). But steam of the temperature of 100° C. (212° F.) can only sustain a pressure of one atmosphere. The water therefore in these deep reservoirs must behave exactly like water, which is exposed in a perfectly closed boiler to a temperature of 100° and upwards. It remains quite liquid, notwithstanding its efforts to form vapour, while the force, with which it presses on the walls of the vessel, increases as the temperature rises. Experimental inquiries concerning steam have shown that its elasticity, that is its power of balancing external resistances increases much more rapidly than its temperature. We know for instance that ice-cold water, and even ice itself, gives off vapour, and that this is the reason why, when placed in open vessels, it is gradually dissipated into the air—that it evaporates. However the elasticity, or expansive force, of this vapour is very slight. To enable water to give off vapour which can resist the pressure of the atmosphere, a temperature of 100° C (212° F.) is necessary. Vapour rising from water heated to 200° C. (392° F.)—a temperature which prevails at a depth of twenty thousand feet below the surface of the earth—has an elasticity fifteen times as great, although its heat is only doubled. At a temperature of 265° C. (509° F.) steam has an elasticity equal to fifty atmospheres; that is, it could sustain the pressure of a water-column seventeen hundred feet high. We have no accurate experiments beyond this; but this is enough to show us that at some depth below the surface of the earth the efforts of the water to throw off vapour must reach the strength necessary to heave up the liquid column that presses upon it, whatever may be the height of that column. At this depth therefore the water must be always kept by the heat of the earth in a boiling state, and therefore must fill any hollows it may find at hand with water in a gaseous state. Calculation, which however by reason of the imperfect data on which it is founded, cannot claim any greater value than that of approximation, places this point for the middle of Europe at a depth of about forty thousand feet, and the corresponding temperature of the water at 414° C. (777° F.) All water that might get down lower than this would be the more certainly turned into steam.

The vapour thus formed rises up in the channels, clefts and hollows, through which the water had run down. But in the higher regions it does not find the temperature which it requires to enable it to support the pressure from above. It therefore is cooled and returns again to the liquid state, just as you may see happen—a short time before the contents begin to boil in a glass retort, filled with water, and set over the fire—to the steam-bubbles as they rise up from the bottom into the upper part of the liquid. By this process the combined heat of the steam is given up to the cooler liquid around it, and gradually heats it until the steam that follows is no longer condensed and can therefore rise to a greater height. In this manner the heat from the depths of the earth passes gradually towards and even up to the surface; the temperature however becomes less and less as it mounts upwards, since the water cannot take any higher degree of heat than that by which, under the pressure which it has to bear, the formation of steam is kept up. For instance, at the depth of ten thousand feet, water may be raised, by the continual influence of the rising steam, up to 353° C. (667°·4 F.), but cannot be heated above this temperature. At a depth of thirty-four feet it cannot be heated above 121° C. (249°·8 F.), nor at the surface above 100° C. (212° F.) As soon then as this temperature is reached, the whole excess of heat of the hot water, that comes up from below, is employed in forming steam, and the liquid at that part begins to boil.

The following table shows the amount of heat which water may acquire, beneath the surface of the earth, from the steam coming up from the depths below.

Depth below surface in feet.	Highest possible Temperature in degrees,	
	Cent.	Fahr.
0	100	212
16	111·7	233
32	120·7	249·3
48	128	262·4
64	134·2	273·5
96	144·4	292
128	152·7	306·8
182	159·9	319·9
224	166·1	331
256	171·6	340·9
288	176·7	350
320	181·3	358·3

It is easy to understand, that steam may force its way even up to the surface of the earth, where-ever the circumstances of the place are favourable to such a result; especially if the branching water-veins reach far enough down, and if the flow of cold surface-water into their upper parts is prevented. The cooling effected by the walls of the water-channel itself is of little importance, for the solid earth can conduct away the heat but in a very slight degree.

Jets of steam (fumeroles) and springs of boiling water come up in many places, especially in volcanic districts. We have numerous instances of this in the Lagoons of Tuscany, on the islands of Ischia, Lipari and Pantellaria; at Baiæ; at St. Germano, near Naples; in the famous Solfatara of Puzzuoli, and in many other places of similar character; at the Peak of Teneriffe; on Jorullo in Mexico, on the island of Iceland &c. There is no country in which springs of boiling water and steam abound more than in Iceland. They have been often examined and described by naturalists; and only lately in the most profound and complete manner by Bunsen. The following account is chiefly extracted from his treatise on this subject.

Hot springs are found at many spots in the neighbourhood of the volcanic rocks of Iceland, often crowded together in great numbers. Here are seen oval basins and great tanks, as it were, made of siliceous tufa, from which the hot water is quietly flowing:—There you find round shafts, of wonderful regularity, from which it is spouting up. Sometimes it shoots up in slender streams from little crater-cones, and is dispersed in foam and vapour. In many of the shafts the sound of the boiling may be distinctly heard in the depths below, without any water coming up; from many of them only a jet of steam gushes forth, often with a mighty roar.

The hot springs of Iceland are remarkable for the quantity of silica they contain, and which they owe to palagonite,—a rock very abundant in this island, but occurring only in a few other places, being a somewhat soluble compound of silica with alumina and alkali. This dissolved silica is the source of the white flint-sinter, which, being deposited by the water about the spring's mouth, gradually raises the ground all round it, hardening it even where it had been formerly a swamp; and so quickly does it spread in some places, that plants still green are found embedded in the flinty mass. Bunsen remarked that by cooling the water no trace of silica was separated from it. Only by evaporating it in a dish some of it was obtained as a fine crust, and that only about the moistened edge of the vessel, where the liquid that had covered it had entirely evaporated, and the liquid itself did not become clouded with the hydrate of silica, till it was very considerably concentrated by evaporation. To this behaviour of the water, Bunsen in part attributes the great variety in the appearance of the hot springs of Iceland. Conceive, says he, a simple petrifying spring which pours out the water from its basin over a smooth, sloping surface of ground; it is clear that the reservoir itself, in which the ever replenished water offers but a very small surface for evaporation, must remain free from siliceous deposits, while its rim, which is just above the level of the water, and over which the moisture is always oozing, quickly and easily dries up, and becomes coated with a crust of flinty matter. A little farther off, where the water spreads itself óver the ground around the spring, this crust increases in thickness as the evaporating surface increases. By this means the ground is gradually raised on one side of the basin, and so opposes an obstacle to the escape of the water in that direction; the overflow is thus transferred to another side which may be a little lower, where the sinter-laying process begins again and goes on, until the change in the level of the bottom causes another change in the place of discharge. Since the basin from which the spring runs receives within itself no share of this incrustation, it keeps gradually growing upwards, while a hillock of flint-sinter is built up around it till it becomes a deep tube. This tube having a comparatively small bore, and being filled with a column of water strongly heated below, and not escaping too slowly, joins in itself all the conditions of a constantly flowing spring, as is observed in many places in Iceland. If now the rising mass of water, ever renewed from below, is heated, in the depth of its self-built shaft, to above 100° C. (212° F.), it must, as it mounts, suffer a continual lowering of its temperature always corresponding to the diminished pressure (according to the table, p. 63), and at last at the surface cannot be hotter than 100° C.

The whole excess of heat above 100° C. must of necessity be employed in generating steam. The water therefore displaced and carried up by the steam given off at the same time at all points, and mingled with it into white foam, gushes up in a constant stream, roaring and hissing from the well's mouth. —This is exactly what may be observed on suddenly opening a valve at the top of a steam-boiler almost filled with water heated far above the boiling-point.

The formation, however, of flint-sinter goes on around these springs unceasingly from year to year. The spring-shaft continues to grow and the ground about it to rise; and the flow of the spring must at last cease, when, perhaps after the lapse of centuries, the ever-increasing weight of the water-column has compelled the liquid to find another escape, or the supply from below may have been diminished, so that in consequence of the cooler water from above continually sinking down, no part of the column of water can any longer reach the boiling-point. Thus great water basins are formed, moulded in solid tufa, and filled with water which is as clear as crystal, and of a splendid greenish-blue, and which either is quite still or runs off very slowly. There are several of these basins near the Great Geyser, and at many other places in Iceland; and in their depths may still be seen the mouths of the ancient spring-shafts.

The grand intermitting springs of Iceland, the

Great Geyser and the Strokkr, have the highest claim on the attention of the observer. The only essential difference, according to Bunsen's account, between these and those that I have just been describing, are the great circumference and proportionally small discharge of the latter. The cylindrical tube of the Geyser built up by the gradual deposition of the flint-sinter is 64 feet deep, by 9·8 feet across. It widens out at the top into a flat saucer-shaped basin of at least 50 feet diameter. Immediately after one of the discharges of the Geyser, Bunsen found this basin empty, and the water standing four or five feet below the mouth of the tube. It required several hours for the basin to become filled again; the water then began to flow quietly over its edge in a little cascade, while the liquid column was heated more and more by the steam or water coming up from below. But the water was considerably cooled at the surface, by reason of the great width of the basin, and the slowness of the overflow. Being thus made heavier, it returned partially into the tube, and made the temperature, to a certain depth within, fall below the boiling-point. On this simple circumstance depends the long period of rest that follows each outbreak of the Geyser. The effect of these two opposite agencies,—the heating from below, and the cooling from above,—may be clearly seen from the following observations of temperature taken at different depths of the water-column during the interval between two following discharges of the Geyser.

Depth below the surface in feet.	Degrees marked by the Thermometer at					
	8½ A.M.		3 P.M.		8 P.M.	
	Cent.	Fahr.	Cent.	Fahr.	Cent.	Fahr.
0	82·6	180·68	85·2	185·36	84·7	184·46
16·5	85·8	186·44	106·4	223·52	110	230
32·5	113	235·4	120	248	121·8	251·24
47·5	122·7	252·86	123	253·4	...	...
62·8	123·6	254·45	127·5	261·5	126·5	259·7

The third of these columns of temperature belongs to the observations made immediately before the second of the two discharges. You will observe, that, just at first, the temperature of the water at the bottom of the tube is above that at which water would boil at the surface, that it decreases always towards the upper parts, where the temperature is necessarily made lower by evaporation. Again the temperature alters but little, both above and below, during the whole time, though in general it rises, while in the middle parts a constant and quicker increase of heat occurs, and at last the boiling-point due to each height is actually or very nearly reached.

Nothing now is required to disturb the balance of forces at once from top to bottom, but a gentle impulse, such as a slight lessening of the pressure from above. This is brought about by the formation of single bubbles, which always occurs before boiling properly commences. The column of water at any given depth, for instance at 32·5 feet, has just reached the boiling-point; therefore the higher temperature of the water rising from below cannot be employed in heating this layer of water any more, so that this excess must give rise to some bubbles, which have elasticity enough to upheave the water above them. That this is taking place may be known by the surface of the water in the basin suddenly rising into a mound. But when these bubbles have reached a layer of water, which is still below the boiling-point, they are again condensed into liquid, and thus the balance is restored. This process is often repeated, each time more quickly following the last, for several hours before the outburst, and is always accompanied with a loud noise, caused by the striking of the water-surfaces where the bubbles are condensed.—By degrees more and more of the column approaches the boiling-point; any steam-bubble now coming up cannot be condensed so quickly, but increases more and more in size as it rises, and at last heaves up the water in the middle of the tube through several feet. A part of the water-column is thus removed; the pressure that restrains the bubbling up of the steam is lessened; and steam must begin to be formed at all parts of the water, which were nearly boiling before. As the bulk of steam in the tube increases, greater masses of water are displaced upwards, and the resistance from above diminishes more and more. Steam is now given off very fast, and sets in motion the water that still remains liquid, which mingled with the vapour is hurled into the air in a mighty jet, ten feet thick, to a height of more than a hundred feet. But this phenomenon lasts only a very short time. The water cooled in the air sinks partly back into the tube; the escape of steam ceases; and all returns again to perfect rest; the outbursts follow each other after unequal periods. It is evident that differences in the rate of cooling from above must have a great influence in causing these variations.

In the other great spring near the Geyser, the Strokkr, the same behaviour may be observed as in the former. But its shaft is not cylindrical, but narrows off towards the bottom, so that the lower opening may be stopped by throwing in turf and stones. There then always follows after a short time a more violent outburst of the water, by which the substances thrown in are hurled up into the air.

Bunsen distinguishes yet another kind of intermittent springs, of which great numbers occur in Iceland, and of which the discharges do not take place in shocks, as is the case with the Great

Geyser, and are not ended in so short a time. They are repeated with great regularity, in some springs in periods of a few minutes, in others of several hours. The spring known by the name of the Little Geyser may be instanced as one of the most remarkable. The mouth of the Little Geyser is in a conical mound of tufa, and is partly covered with stones. Between these stones, which at certain periods are left uncovered by the water, the jet of boiling water forces its way from time to time. The discharges, at the time of Bunsen's visit, were repeated with great regularity after periods of three hours and forty-five minutes; the chief outburst, which far surpassed all the others in extent and beauty, taking place between nine and ten o'clock in the morning. Its approach makes itself known by a gradually increasing escape of steam, and by a splashing of water under ground. Then hot foam is thrown out with the steam in jets, which rising and falling slowly at intervals, keep mounting higher and higher, until after about ten minutes, when the phenomenon has reached its greatest development, they shoot up in bundles, as it were, spirting upwards and sideways to a height of thirty or forty feet. Then the jets dwindle again in size and height, just as they seemed to grow before, until, after another ten minutes, the spring is again entirely at rest.

For the explanation of these periodical discharges, Bunsen is inclined to adopt the assumption, suggested before him by Mackenzie and others, of underground hollows, into which both water and steam find their way at the same time. The water is heated to boiling, by the steam, by the gradually increasing elasticity of which it is forced out: just as the water is driven out of a fire-engine by the expansion of the air condensed in the air-chamber.

Since the manner in which steam acts in giving rise to the hot springs of Iceland, has been cleared up for us with certainty, we are entitled to conclude, that the same agent has a share in producing many other hot springs; such, for instance, as are not in the neighbourhood of high mountains, of which the nearly boiling springs of the islands of Ischia, Lipari, and Pantellaria are examples; near which besides, and that generally in spots lying higher than the springs, jets of steam (fumeroles) are observed. Even many springs that are not quite so hot as these, such as those of Aix-la-Chapelle, Burtscheid, Chaudes-Aigues, &c., seem to depend on the action of underground steam.

LETTER VI.

JETS OF GAS AND MUD VOLCANOES.

The agency of carbonic acid gas in giving force to the flow of springs, is very similar to that of steam. Water, when it is brought in contact with carbonic acid, is able to dissolve a quantity of that gas in bulk somewhat greater than itself. For instance, one cubic foot of water takes up one cubic foot of carbonic acid, and that without much increasing its own bulk. This proportion of solubility is always the same for carbonic acid, whatever may be its density. Since now this gas, like any other, is condensed in proportion to the pressure it sustains, it follows that water can take up so much the more of it by weight, the greater the pressure from without, under which the solution goes on. For instance at the depth of six hundred and eighty feet, or under the pressure of a water-column of twenty atmospheres, water can dissolve a portion of carbonic acid twenty times as dense as at the common pressure—a quantity, whose bulk, it is true, is still equal only to its own—but whose weight is twenty times as great as that which it could dissolve in the open air. If now the pressure is lessened to one-half, one-half of the dissolved gas escapes from the liquid, because this gas, if it were not dissolved at all, would occupy twice as much space as the water fills, while the water can still only dissolve and keep in solution a bulk of gas equal to its own.

Let us now suppose, that water, which in the depths below has become more or less strongly charged with carbonic acid, reaches, in the channel that gives it vent to the surface, a height, at which the pressure from above is less than the elasticity (or effort to return to the gaseous state) of the carbonic acid. The gas now releases itself, and, pushing before it a certain quantity of the liquid, forces its way, mixed with the water, up the vent-shaft;—just as you see it doing when a bottle of champagne is opened. There are here again, you observe, all the conditions, whose presence in the hot springs of Iceland I have explained; with this difference only, that there steam, and here another gas, carbonic acid, is the moving power. You will now understand that the springs may be forced up by the joint power of water-pressure, and of the expansion of the gas, or even by the latter agency alone. And this will probably be determined by local circumstances, such as the depth from which the water rises, the width and shape of the channel, the quantity of gas held in solution, the temperature, &c. The water so sent up, may rise above the surface of the earth in a uniform constant jet, as from the bored spring-well at Nauheim, or in an intermitting stream, as at Kissingen, or in a jet continuous but varying in height, as from the "Sprudel" of Carlsbad.

Carbonic acid issues from the earth in numberless places, even without its usual accompaniment of water. Such jets or springs of gas are called *Mofetti.* Wherever they come up, they are destructive of the life of plants. Spots therefore, in which carbonic acid is thrown off in large quantities, are always marked by being devoid of verdure. They are met with especially in places where volcanoes are still at work, or where there are still traces of ancient volcanic agency: for instance in the Eifel, in the Weser hills, in the Wetterau, in the neighbourhood of the Bohemian baths, in Auvergne, &c.

At Saatzen and Istrup, on the table-land of Paderborn, the carbonic acid rushes with great force from a thousand ventholes in the ground. In a swampy place near Istrup, mounds of mud, from fifteen to twenty feet in height, and at least a hundred feet round, have been thrown up by these gas-streams: and on their surface there are numberless little basins or pools, in which the water is always kept in a state of violent agitation by the rising of large gas-bubbles. In the valley of the Brohl, in the Eifel, a single gas-spring gives off daily about five thousand cubic feet of carbonic acid, and the numerous jets in the Eifel, taken altogether, are said, on a rough reckoning, to throw up about five million cubic feet, or about three hundred tons of gas a-day. To get as much of this gas by burning wood, it would be necessary to use up daily twelve thousand cubic feet of hewn wood.

However, these enormous quantities of unbreathable gas are very quickly dispersed, as they escape into the open atmosphere, and have no perceptible effect on the condition of the air. In places, that are more shut in, the carbonic acid collects about the ground, because it is heavier than the air, and for this reason, if not mixed with the air, falls through it like water. In caves and in deep hollows, in which there is always a plentiful and uninterrupted discharge of carbonic acid, such as the famous Grotto del Cane near the Lake of Agnano, a few miles from Naples, and the Dunsthöhle near Pyrmont, the ground is always covered to a depth of some feet with this heavy gas. If a large soap bubble is allowed to fall through the air of these caverns, it begins, on reaching the top of the layer of carbonic acid, to sway up and down, like a piece of wood which is let fall from some height into the water, and than it quietly floats upon the gas until it bursts. Animals placed in the vapour must be stifled, unless their heads reach above its upper limit.

The Valley of Death, a deep hollow discovered by modern travellers in the island of Java, probably owes the noxious influence, which it exerts on all organic life, to carbonic acid given off from the ground.

Discharges of carbonic acid, lasting only for a short time, follow regularly in the train of volcanic outbursts. In the neighbourhood of Vesuvius this gas is thrown up in vast quantity from crevices and hollows, generally not till some weeks after the outburst, and a little later cease altogether.

In many places carbonic acid breaks forth from the earth, mixed with steam. Some of the most remarkable instances of this are given by the Lagoons of Tuscany; they lie in a hilly district, several leagues round, in which grows no kind of herb, and which is always shrouded in a white, noisome mist. The ground is for the most part sloping, and the soil loosened by the streams of gas and vapour, which burst out from numerous shifting holes. In some spots the surface is dry, and often burning hot, in others it is covered with muddy pools—the Lagoons. In many places one finds at a little depth, a muddy mass half liquid with hot water, into which the seeming hardness of the surface keeps one in continual danger of breaking through. The steam and gases rush up with great force, partly out of clefts and openings (called *Suffioni*) in the hard crust, partly out of the midst of the little pools, agitating the liquid, and hurling mud and water into the air. These vapour-jets have become very important to the arts, from the boracic acid, a substance contained in borax, which they bring up from below and leave behind in the water of the Lagoons. This boracic acid is recovered from the water by artificial evaporation. There are ten manufactories, established for this purpose, scattered about the neighbourhood; these yielded altogether in the year 1846 about a thousand tons of crystallised boracic acid. The evaporation goes on in pans, which are kept hot by the jets of steam from the ground, which have, it is said, a temperature of from 97° to 100° C. (206°·6 to 212° F.)

In certain other districts the vapours issuing from the ground are mixed with (besides carbonic acid) sulphuretted hydrogen, sulphurous acid, and even with the vapour of sulphur: the quantity of this latter, thus brought up, is certainly but small, yet easily recognised by the peculiar smell, and by the masses of it that are deposited in the course of time. These are the *Solfataras.* Among those best known is the Solfatara of Puzzuoli, which is covered with sulphurous fumeroles; but precisely similar features are met with in other volcanic districts. Bunsen says of the Solfataras of Krisuvick and of Reykjahlid,

—the most remarkable ones in Iceland,—that jets of sulphurous acid, sulphuretted hydrogen, sulphur and steam burst forth in wild confusion from the hot soil of palagonite-tuff, and spread far over the steaming 'sulphur-grounds,' which are in continual growth from the mutual decomposition of the palagonite* and of these gases. The outbursts of gas and vapour on these surfaces are of the most various character. The curious traveller must not venture to walk here without the greatest care for his footsteps, lest the treacherous ground of clay and sulphur should let him sink through into the hot mud. On the slopes of the mountains, where a layer of a harder stone prevents the solfataras from spreading farther in the same manner, they gush out from clefts and crevices in the rock, in the form of mighty jets of steam, roaring and hissing, or, if they break forth from the openings of underground caverns, their deep-mouthed bellowing is truly awful.—Where, on the other hand, the spring-channels lead down towards the valley-bottoms, among the looser tuff-rock, boiling pools of mud are found, in which a disgusting bluish-black clay-slime keeps rising up in large bubbles, which, as they burst, hurl up the boiling-hot mud often to a height of some fifteen feet, and heap it up into a crater-like wall round the basin of the spring. All these features of the landscape taken as a whole, present a picture of the wildest desolation, set as it is in a frame of the gloomiest rock-land, which surrounds the desert scene, and increases the depth of the dreariness.

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* Palagonite is a rock composed of silica, alumina, sesquioxide of iron, lime, magnesia, potassa, soda, and water; it is abundant in Iceland; it cannot resist the action of the weakest acids, and is even partly soluble in water.

Since the sulphuretted hydrogen only appears mixed in small amount with the carbonic acid and steam, there is reason to believe that it is formed by the passage of the water-vapour, and carbonic acid gas, over sulphuretted metals, such as the sulphides of calcium, potassium and sodium. The sulphurous acid, wherever it does come up, arises, doubtless, from the burning of sulphuretted hydrogen, or of sulphur previously uncombined. The sulphurous acid and sulphuretted hydrogen, being brought into contact by the aid of water, are changed by mutual decomposition into water and sulphur; and thus these gases, when they come forth together from the fumeroles, are always accompanied by sulphur. But the sulphuretted hydrogen gas mixed with steam, also suffers a slow decomposition, by the presence of air, whereby its hydrogen is oxidised into water, and its sulphur is set free. This then at once explains the gradual spread of sulphur over the solfataras.

The wide distribution of these discharges of carbonic acid gives us reason to conclude that they owe their origin to some cause, whose action is universal, and their general occurrence in volcanic districts, and in company with steam, suggests the conjecture, that this gas is formed, at least in part, in the bowels of the earth, under the joint influence of steam and a high temperature. In fact the limestone strata, which in many places reach to great depths, afford boundless stores of carbonic acid. Limestone, heated in a closely shut place does not, it is true, part with its carbonic acid. But if the red-hot stone is subjected to the action of some other substance, which can combine with the caustic lime, instead of the carbonic acid, such, for instance, as silica (silicic acid), the gas is given off. Or if the lime is exposed to a blast of steam, which immediately carries off every particle of carbonic acid as soon as it is set free, the latter is readily driven off, and can then find its way to the surface, either with the steam, or, if the steam should be condensed by any cooling agencies within the earth, it passes off dissolved in the water, or lastly, it escapes by itself in the gaseous state.

Another source, not quite so deeply seated, of carbonic acid gas is presented by the numerous beds of the remains of plants that lie stored up in the earth. Plants and parts of plants, which have lost every trace of life, when in contact with water soon pass into a state of gradual decomposition, which ends at last, after the long continued action of the air, in their complete destruction, and conversion into carbonic acid and water. This is one of the commonest causes of the formation of carbonic acid in the air, and in the upper strata of the earth, so far down as the atmosphere can penetrate. But even where the free entrance of air is hindered or altogether shut out, the remains of plants undergo a gradual decomposition, which goes on more or less quickly according as the temperature is higher or lower: but in this case the changes run a different course.

The substance of wood is, as you are aware, made up of carbon, hydrogen, and oxygen. A part of the carbon goes off, in combination with a due proportion of the oxygen, as carbonic acid; another part of it unites with hydrogen to form hydrocarbon gas (marsh-gas). This latter compound, however, is not formed so plentifully as the carbonic acid, at least at first, and where the stages of decomposition are not hastened by the aid of heat, or by such a fine state of division of the remains, as obtains in marshes. For this reason, during the first period of the changes, the amount of oxygen in the woody mass is lessened, and the proportion of hydrogen with respect to the carbon and oxygen is increased. The various sorts of brown-coal are still in this first stage of change. They contain less oxygen but more hydrogen than does wood. The so-called *Choke-damp*, which occurs in the English coal mines, as well as in those of the brown-coal, which is so abundant in some parts of the continent, consists of discharges of carbonic acid with a little marsh-gas, which often pour forth from clefts accidentally opened in mining, and is a proof that this process is going on in the coal-beds, though but slowly. The more the oxygen is withdrawn from the brown-coal, the nearer does the condition of the latter approach to that of common or true coal, which, being of much more ancient origin, generally lies far deeper in the earth. That similar changes have been, and are still, going on in peat-bogs, is certain from the different features of the peat, at different depths in the beds; though, from their open position at the surface, gases, which are given off from the decaying turf, cannot become stored up to add their evidence as to the stages of the process. In common coal there is no, or but very little, oxygen, while it is richer than brown-coal in hydrogen. However carbonic acid is also still given off from the beds of true coal, under the action of the oxygen of water. And then carburetted hydrogen (chiefly marsh-gas), the formation of which from the hydrogen of the water is very much favoured in the deeper beds by the influence of high temperature, comes off in greater quantity; so that, indeed, the gases issuing from open clefts may be set on fire, and will then burn as a jet of flame. If a discharge of this inflammable gas takes place into the mine, without being found out in time, and if it gets mixed with enough air to burn it, a flame, that may be kindled by a candle or lamp at any one point, flashes in an instant through the whole of the mixed atmosphere. The most fearful shocks and explosions, too often attended with great sacrifices of human life, ensue from accidents of this kind, which are generally owing to the carelessness of some of the workmen themselves. This is the so-called *Fire-damp*.

The inflammable gases, which here and there have been known to escape from shafts and borings, and which in many places issue from clefts and natural openings in the earth, have always proved, whenever they have been analysed, to consist chiefly of carburetted hydrogen mixed with more or less carbonic acid. We are acquainted with a pretty good number of natural jets or springs of combustible gas. Among the best known are those at Pietra-Mala, not far from the road between Florence and Bologna, and the Holy Fires at Baku, near the Caspian Sea, which are still objects of reverence to some of the inhabitants of the district.

At many spots around Baku the inflammable gas has to work its way up through a mass of mud. It there throws up little conical hillocks, with funnel-shaped openings at their tops; these are filled with liquid mud, through which the gas rises in bubbles, sometimes casting up mud and stones.

Lenz saw, on the mud-plains of Baku, a great number of these cones, about two feet high, standing near each other. Such spots as these, which throw up liquid mud, are called *Mud-volcanoes.*[*] There are many of these in various countries; for instance in several places in Italy; at Maina, not far from Modena; at Querzuola, in the neighbourhood of Reggio, &c.; again there is the Macaluba, a hundred and fifty feet high, near Girgenti in Sicily; and the famous mud-volcanoes, in the Crimea, and in the neighbouring peninsula of Taman, &c.

The several outlets, which the gas has bored for itself in the mud cones, seem sometimes not to be enough for the escape of the stores of highly elastic gas that are shut up within. Violent outbursts then take place, accompanied with a roar that may often be heard at a great distance, and with vast discharges of mud and water. In an outburst of Kuku-Obo, in the peninsula of Taman, in the year 1794, about twenty-six million cubic feet of mud were poured forth.

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[*] The water thrown up from these mud-volcanoes often tastes strongly of salt. Another substance that very commonly comes from them is *petroleum,* or earth-naphtha; some of it is flung up with the mud, and some is found flowing out of the earth, in the form of springs, in the neighbourhood.

LETTER VII.

VOLCANOES AND EARTHQUAKES.

In my last letters I have given you numerous and well-marked proofs of the mighty effects of elastic vapours and gases at work at but moderate depths below the surface of the earth. You will now be prepared to consider it probable, if not quite certain, that at greater depths this expansive power must be enormously increased, in consequence of the proportional increase of heat. And you will readily conceive that this upheaving power may at last become so great, as to counterbalance the pressure of thousands of atmospheres, or even the huge weight of the strata of the earth's crust.

I have before shown, that, at a certain depth, which may be taken at about forty thousand feet, an expansive force must be given to the vapour of water, strong enough to enable it to upheave the whole liquid column that presses on it. I showed too, that whatever water may find its way to a depth greater than this, must be always in a boiling state; that is, that the heat which it takes up from the earth must immediately turn it into steam. If, however, the steam given off under these circumstances cannot escape through the upward outlets so quickly as it is supplied, the formation of vapour ceases, the temperature of the water rises, and with it the elasticity of the steam. If, now, the conditions are such, that the resulting pressure can be transmitted downwards as far as to the red-hot molten masses in the bowels of the earth, some of this latter must be set in motion, and, if there are any available channels in the strata, must be forced up to the surface, just as certainly, and just in the same manner, as springs of water are raised by weaker forces acting at less depths. Naturalists seem at present very generally in favour of the view that volcanic outbursts owe their origin to forces of this kind.

This belief is strongly supported by the numerous hot springs and steam-jets that are met with in the neighbourhood of nearly all volcanoes, and by the fact that volcanic discharges are always accompanied by enormous quantities of steam, which force their way through the liquid masses of lava, and take the form of clouds, which, overhanging the crater, often give rise to sudden storms and floods of rain.

Even the smoke of volcanoes, during their state of rest, consists in great part of steam, which, according to the less or greater difficulty which it finds in making its escape, sometimes puffs out quietly, sometimes hurls up stones and earth, as is seen to take place in the Geysers, in which it can even be caused by throwing stones into their mouths.

Since the discharge of melted rocks is always attended with outbursts of steam, we may assume that a great deal of steam must come up, mixed with the liquid stone, through the vent-holes of the volcanoes; and that for this reason the upheaved column of lava has far less weight, than we might suppose it to have from its density when solid, although its mass, even in this state, is thoroughly filled with bubbles. Besides, it is likely that the lava of volcanoes, that are still active, comes from a much less depth than might be imagined from its melting temperature, which, according to Bischof, is between the melting-points of silver and of copper. For it is very possible that the water that penetrates into the deepest clefts, and is there brought up to a red heat (in places, where by the excess of pressure from without, or by the narrowness of the outlets, the formation of steam may be hindered or retarded), imparting its heat to the strata lying above, and gradually melting the most fusible parts, may thus at last bore a passage for itself, through which it rushes, carrying with it the melted mass, and the loosened earth.

According to this view, volcanoes are, as Krug von Nidda long ago expressed it, nothing but huge intermitting springs, from which, instead of water, liquid lava flows.

Under the name of volcanic phenomena, we include all those mighty exertions of underground forces by which,—from openings torn in the earth's crust,—streams of fire, smoke, and ashes (that is, fine red-hot sand and dust) are thrown up often to an incredible height, and glowing slags and stones, and even great pieces of rock are hurled forth; copious streams of lava, or melted mineral matter, and in many cases enormous quantities of mud and water are shot forth; sometimes hills have been lifted up in valleys and plains, and islands have been thrown up in the sea.

Numberless instances of such phenomena have occurred within historical times, and are still repeated every year.

In by far the greater number of cases, the outlets of this volcanic activity have served for only one discharge. They become stopped up again, when the force from below has exhausted itself for the time. When the elastic powers within have recovered themselves, they find vent by some other way. Here and there, however, some lasting channels have been established from the interior up to the surface. These form, as it were, the chimneys of the fire-places underground, and are called especially *Volcanoes,* or *Burning Mountains.*

There are at present at least a hundred and sixty, of great activity, scattered over the earth. Several of them seem to be, as it were, the fiery centres of a volcanic district surrounding them in circles of greater or less extent. They are generally the loftiest peaks of whole groups of craters which are crowded together, and of which one or another has at some time shown signs of activity. Such are called *Central Volcanoes.* Instances of these are —Vesuvius, being about three thousand eight hundred feet high, and the only volcano that still remains active on the continent of Europe; Etna, which is about ten thousand five hundred feet high; the still loftier Peak of Teyde, in Teneriffe; the Pico of the Azores; Mowna Roa, in Owyhee, the highest known island mountain, reaching, according to some measurements, to a height of fourteen thousand feet; the volcano of the Isle of Bourbon, famous for its frequent and mighty outbursts; and several others. Mount Erebus, too, about twelve thousand five hundred feet high, discovered only a few years ago on the Antarctic Ocean, under south latitude 78°, is probably a central volcano.

In the case of the smaller crater-cones, which surround the central volcano, we know generally of but one outburst of each of them, and that the one to which they owe their origin, and before and after which the volcanic agency has found itself an outlet at some other point more or less distant. Thus, says Leopold von Buch, the whole group of the Canary Islands rests upon one volcanic hearth, over which each of these islands was heaved up from the bottom of the sea.

The power which can bring about such vast movements, must be a long time brooding and gathering itself within, before it can vanquish the resistance of the masses that are pressing it down. At last it tears open the strata which form the bed of the sea, and those that lie deeper down below it, and uplifting them to the surface, escapes through the openings thus made—the so-called *Craters of Elevation*, or *Upheaval*. However, a great part of the huge uplifted mass falls back again, and soon shuts the opening, which would not have been formed but for the enormous force that rent it. No volcano is produced; but the basalt rocks that were forced up generally remain around the outer border of the crater, as witnesses of the outburst that once had happened. The Peake of Teyde rises up in the midst of such a crater of upheaval of vast circumference, as a lofty dome of trachyte. Through the opening in its summit there is formed, between the atmosphere and the depths within, a channel which can be sealed at top, but not below, by the cooling and falling in of the melted masses. Similar outward features are found on all other central points of volcanic activity. Their craters are the especial outlets of the elastic forces generated within their volcanic region. The liquid masses (lavas), set in motion by these forces, are urged in greatest quantities towards the volcanic cone, as the point of least resistance, and then flow out of the crater, unless, as is very often the case—especially with lofty volcanoes,—they first burst an outlet for themselves at the foot of the mountain.

All that has been observed of Vesuvius confirms the view, that, with the Phlegrean Fields of Puzzuoli and with the neighbouring islands, it forms a single volcanic district, of which the mountain itself is the centre, and that any outburst, at any spot within this circle, tends to prevent another from happening at any other part of it. While a stream of lava was running from the mountain Epomeo, on the isle of Ischia; again, when the Monte Nuovo started up in the Lucrine Lake, in 1538; and during the time when volcanic action was going on in the Phlegrean Fields; Vesuvius remained at rest, and was covered with forests, and inhabited. Since Vesuvius has been constantly at work, the islands and the crater near Puzzuoli seem to have been perfectly quiet.

A great number of volcanoes often lie in a line one after another, on a long cleft rent through the crust of the earth; and they are often grouped in double rows or chains, which bound valleys of greater or less extent. Such are called *Chain-Volcanoes.*

To this class belong the numerous volcanoes of Iceland, of which at least seven are still at work: on the north-east, Krabla, Leihrunkur, and Trölladyngur; on the south-west, Hecla, Eyafiäll, and Kötligia; on the east, Oeräfa-Jökul, five thousand six hundred feet high, the highest mountain in Iceland. But in other parts of the volcanic belt that runs across this island, enormous clefts have been torn open, from which streams of lava pour forth in masses of such length and breadth, as have not been found in any other volcanic country.

The Lipari Isles again seem to be but the loftiest crater-crests of a volcanic tract of considerable length. However, only two of these can be counted among the volcanoes that are still active, viz., the never-resting Stromboli, and Volcano.

The western row of the Lesser Antilles forms a connected chain of volcanic islands: among these Guadaloupe, St. Christopher's, Martinique, and St. Vincent have the most remarkable volcanoes.

On the continent of America are a great number of burning mountains, which rise up on the ridge of the Cordilleras, and generally form the highest of their crests. They are chain-volcanoes. Such are the long row of volcanoes of Chili, several of which are among the most active, and of which Aconcagua, nearly in the latitude of Valparaiso, is twenty-four thousand feet in height. These volcanoes stretch almost in a straight line, running along the coast from 46° to 27° south latitude. Farther north, in the Andes chain, lie the lofty volcanoes of Bolivia and Upper Peru, one of which is Arequipa. The high land of Quito, which HUMBOLDT speaks of as being an enormous volcanic vault, is bounded by two rows of burning mountains, among which are the famous Sangay, Tunguragua,* Cotopaxi (18,775 feet), Antisana (19,000 feet), Pichincha, and Imbaburu. The volcano of Tolima also belongs to this row. The underground fire, says HUMBOLDT,† breaks forth sometimes from one, sometimes from another of these openings, which are usually supposed to be separate volcanoes.

The free state of Guatemala, in Central America, lying between the northern and southern continents, is especially remarkable for the great number of volcanoes, about forty, which are there crowded together. All these fire-mountains follow the various bends of the Cordilleras, in an almost unbroken row. They all probably lie over a vast cleft torn by the underground forces, of which they form the outlets to the atmosphere.

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* Opposite Tunguragua, on the eastern side of the two volcanic chains, lies Chimborazo, which, however, has no crater.

† HUMBOLDT remarks, as a proof of the uninterrupted continuance of the activity within, even when actual outbursts from the volcanoes are not going on, that, during his long stay at Quito, not a month passed that awful noises, with or without earthquakes, were not heard from beneath their feet.

The row of Mexican volcanoes,—amongst which the lofty cone of Colima, the ever burning Popocatepetl, seventeen thousand feet in height, and Orizaba, but little less in height, are universally known,—does not follow the line of the Cordilleras, but runs across the narrow part of the continent, from the Pacific Ocean to the Gulf of Mexico.

On the peninsula of California, and, farther to the north, along the west coast of North America, several volcanoes are known, some of which are still smoking, and some perhaps extinct. The chain stretches through the peninsula of Aliaska to the Aleutian Islands; and the active volcanoes of these islands seem to show that there is a connexion with the numerous and mighty fire-mountains of Kamschatka. These latter run in two rows, side by side, from 57° north latitude, down to the southern point of the peninsula, from which the line stretches on over the chain of the Kurile Islands, and of those of Japan, and thus encompasses the whole east coast of Asia, through the volcanic ranges of the Philippine Islands, of the Moluccas, and of the Sunda Islands, with an almost unbroken volcanic girdle. The islands of Niphon, Luzon, and Java, are the chief seats of the volcanic activity of this line. In the latter island, in particular, more volcanoes are crowded together than in any other country in the world; for more than a hundred may be counted there, and thirty of them in full activity. The great volcanic chain of Sunda, beginning with the burning mountain on Barren Island, to the north of Sumatra, runs through Sumatra, Java, Bali, Lambock, Sumbava, Flores, and many little islands, to Banda, Amboina, and Gilolo, and so farther on to the Moluccas and Philippines. At the same time, in an easterly direction, it joins the so-called Australian Volcanic Chain, whose crater-cones rise in the islands New Guinea, New Britain, Sòlomon's Island, and the New Hebrides, and is continued by some single volcanic islands to the volcano Egmont, in New Zealand. These, with the burning mountains of the Sunda Islands, form a broad curve that encompasses New Holland on the east and north.

Many of these volcanoes are always throwing forth columns of vapour. Their actual outbursts seldom, however, last longer than a few hours, though they sometimes extend over several days, and even weeks, and are not then repeated till after longer intervals. Thus the Peak of Teyde discharges itself once, or at most twice, in a hundred years. The volcanic cone of Tolima had been at rest for two centuries, when a violent outburst in November, 1827, showed that the internal forces were still at work. Again, Imbaburu had long been considered as extinct, when in the year 1691 it overwhelmed a large tract of land with a discharge of mud and water. The outbursts of some other burning mountains are more frequent. Thus of Etna, sixty are known to have happened within two thousand years. Vesuvius has been at least eighty times in violent action since the first eruption, of which we have so lively a description by Pliny the younger; and during the present century it has scarcely ceased to vomit fire. We know of twenty-five outbursts of Hecla having been recorded since the beginning of the eleventh century: the last, which commenced in 1845, was still going on in the autumn of 1846. Gonung Api in the isle of Banda, and Tofua in one of the Friendly Islands in the Pacific, have been throwing up red-hot matter ever since we have known them. The little volcano of Stromboli, too, is remarkable for having been in restless activity, so far as we know, for a thousand years. It throws up slags and pumice-stone at intervals, usually of a few minutes, with greater force at certain periods; but the quantity is comparatively small, and is seldom accompanied with lava.

The ordinary action of Vesuvius consists only in throwing up vapours and stones, which are sometimes piled up in conical heaps within the crater, which is sixteen hundred feet wide. In the more violent convulsions of the mountain these discharges are more and more increased, and pass at last into an uninterrupted stream of fiery masses hurled into the air. Lava now gushes forth from the mountain's throat, with the never-failing vapours, and fills the crater to overflowing; or it breaks forth from other spots on its side, with an awful noise, making the mountain tremble, while red-hot matter is still shot forth from the crater. However, the outbursts do not always go so far; for the volcano generally returns to rest after a short period of activity, not quite so violent as this, and the red-hot melted matters cool and solidify in the crater. However, there have been many instances, even in very modern times, of destructive outbursts of Vesuvius.

The outbursts of 1805 and 1822 are especially remarkable for the enormous quantity of ashes thrown up. On the 24th of October, 1822, nearly the whole country round was shrouded in the thickest darkness, by a cloud of ashes cast up from the crater, and people were obliged to go about on the roads with lanterns. On this occasion the noise within the mountain was so loud that the ceilings of the apartments in the palace at

Portici were split by the mere concussion of the air. The ground of the neighbouring country was covered with ashes to a depth of fifteen or eighteen inches. Before the discharge a cone of slag four hundred feet high stood in the middle of the crater; this fell in all at once at the beginning of the outburst, so that the bottom of the crater is now seven hundred and fifty feet lower than its northern border, above which this cone had before towered more than a hundred feet.

On the 16th of June, 1794, after the mountain had been quaking and groaning awfully for several days, a vast stream of lava burst from a cleft in its side, and gushed, with a breadth of several miles and a depth of forty feet, over the fruitful and well-cultivated district below it, sweeping away churches, convents, villas, and everything that stood in its course; it utterly destroyed the rich and flourishing town of Torre del Greco, which at that time held eighteen thousand inhabitants; and at last poured itself, hissing and roaring, into the sea. The loss of human life was small, for it was easy to flee from the glowing flood as it slowly rolled along.

From Etna, too, but very lately, in the years 1832 and 1842, there were violent outbursts; but for a very long time past the lava has ceased to be poured from the summit of this lofty mountain.

Streams of lava have never, or but very seldom, been known to come from the towering volcanoes of the Andes. From them, however, there are thrown up from time to time discharges of ashes, and floods of mud and water, that surpass belief, laying everything waste before them.

L. von Buch gives the following account of one of the most destructive volcanic outbursts of modern times. "On the 8th of October, 1822, about one o'clock in the afternoon, a frightful noise was heard in the neighbourhood of Galung Gung, in Java; the mountain was immediately shrouded in a thick cloud of smoke, and streams of hot sulphurous muddy water poured down its slopes on every side, and carried before them everything they met with. There was then an awful sight in Badang, the river Tschiwulan sweeping down vast multitudes of corpses of men, cattle, rhinoceroses, tigers, antelopes, and even entire houses carried with them into the sea. This flood of hot muddy water lasted but two hours; but these were enough to lay waste a whole province. At three o'clock it had ceased, but there now followed a thick rain of ashes and pumice, which utterly destroyed all that had been spared of the face of the country, and burnt up all the trees. At five o'clock all was at rest again, and the mountain was seen once more. And during this short time every dwelling, every village, for many miles round, had been covered with mud; in places which just before had been level plain, hills had arisen, and a vast number of human beings had ceased to live."

One of the most remarkable instances of volcanic activity, both in regard to the quantity of matter thrown up, and to the magnitude of the accompanying phenomena, was an outburst of Cosiguina, in Nicaragua, a volcanic hill, only five hundred feet high, standing on a tongue of land in the Bay of Fonseca, on the Pacific coast. This began on the 20th of January, 1835,* and lasted several days. The discharge of ashes and pumice was so frightful, that the country round, over a space forty-three leagues across, was wrapped in impenetrable darkness. The shore of the headland was pushed eight hundred feet out into the sea by the fall of ashes, and two islands of slag and cinders were thrown up in the bay. The fine dust was carried by the wind as far as Jamaica, where it fell in various places on the 24th and 25th of January; and an English vessel fell in with a great quantity of floating pumice out at sea, at a distance of eight hundred miles from the volcano. The outburst was accompanied by an earthquake, which was felt over the whole isthmus. So mighty was the roar, that it was heard not only in the towns of Guatemala, St. Salvador, Leon, and at Balize, on the eastern coast, in the Bay of Honduras, but, by the sound travelling through the solid earth, even at Kingston in Jamaica, at Carthagena, and Santa Marta, in New Granada, and at Santa Fé de Bogota, although the latter town lies a thousand miles from Cosiguina. At several of these places, to which the trembling of the earth did not reach, people thought they heard discharges of cannon. "To get a good notion," remarks Berghaus, "of what the awful thunders of the mountain during its outburst must have been, you must fancy the noise of Vesuvius, which in fact is not perceived farther off than Gaeta, being heard at once in Lisbon, Liverpool, Gothenburg, Riga, and at the foot of the Caucasus."

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* It is certainly worthy of note, that at the same time Aconcagua, which had been considered as extinct, as well as Osorno, both in the Chili range, burst forth; and that a month later, on the 20th of February, while Cosiguina was still at work, the volcanoes in the whole range of the Chilian Cordilleras shot forth fire, and that a volcanic outburst took place in the sea near the island of Juan Fernandez. Chili, and the island of Chiloe, were shaken by an earthquake; their coasts were permanently heaved up, and Conception, and all the neighbouring towns in Chili, were destroyed.

If we consider the enormous quantities of earth which are heaved up and thrown out by volcanic outbursts—masses which cannot fall back again into the depths within; if we remember that actions of this kind have been witnessed for thousands of years, that by them mountains have been made to rise, and valleys have been filled up; if, at the same time, we reflect upon the wide distribution of the volcanoes, and their behaviour altogether; we must conclude that, in volcanic districts there must be enormous tunnels, and those at very great depths, because they do not impair the general firmness of the outer crust of the earth.

More convincing proofs of the existence of deep underground channels, filled with liquid, are derived from the earthquakes that are often felt at the same time over vast tracts of country. The frightful earthquake, by which Caraccas was destroyed in 1812, was felt at the same time over a space a thousand miles across; and the still more awful shocks by which, in 1755, Lisbon was laid in ruins, and a great part of the city sunk in unfathomable depths, were perceived at the same time on the coast of Africa, in the Canary Isles, in Ireland, and even at many places in Germany. Neither can we doubt that the earthquake in Chili, the discharge of the neighbouring volcano-chain, the rising of the land around Conception, and the volcanic outburst at the same time near Juan Fernandez, were but parts of one great convulsion.

These, and a great number of similar actions, can only be explained by supposing that there are vast branching tunnels under whole continents, stretching even under the bottom of the sea, and leading deep into the bowels of the earth.

Any violent blow struck upon the ground causes the place, as you know, to tremble. The fall of a wall, or of any building, the blasting of a rock, even the rolling of carriage-wheels over a paved street, may be felt at some distance, through a slight motion of the ground: in the same manner must underground movements become perceptible. Thus the shock given by the discharge of the Geyser is felt especially just around the spring, and during an outburst of Vesuvius the whole mountain, and often even the country around at some distance, is affected with a trembling motion. But such shakings of the earth are the usual forerunners of volcanic discharges; and if we believe that we are justified in ascribing the latter to the powerful expansion of elastic gaseous bodies, it would be illogical to seek for another cause for the explanation of the former. We may consider them as the endeavours of the vapours confined in the depths below to force for themselves an escape upwards; endeavours by which they enlarge the channels under the earth, and set in motion the moveable masses within them, water and melted rocks, and, here and there, perhaps, heave up and rend the solid crust of the earth, and at last break their way out from their confinement.

The frequent occurrence of earthquakes, especially in volcanic regions, gives us reason to believe that, the underground forces are in a state of ceaseless activity, which from time to time results in volcanic outbursts. It is commonly observed, too, that, while frequent shocks occur as the forerunners of an outbreak, it is followed by a long period of rest, until by degrees the hollows in the earth may become again filled with water and steam, and these, by the gradual rise of temperature, may again reach the bursting pitch of elasticity. It will often have been remarked, that the most violent shocks occur in volcanic districts at those times, when, by the gradual stopping up of the crater-mouths, a limit has been set to the continual escape of the great masses of vapour. At all events this fact agrees well with the property, which, as you know, belongs to hot water—that while the formation of steam continues, it cannot get above a certain temperature, whatever the heat of the surrounding matter may be, and that, therefore, it cannot attain an elasticity greater than that corresponding to this temperature,—and that, if the escape of steam is quite stopped, the water at last must take the temperature of the neighbouring bodies.

The same underground forces, which in volcanic districts throw up lava and ashes, and heave up the ground, may, by means of the fluids which are within the earth, transmit a part of their action to regions in which volcanic outbursts are quite unknown.

Any shaking given to a surface of water, for instance, by a stone thrown into it, gives rise, as you know, to a set of waves, to an alternate rising and falling of the liquid mass, which is sent onwards in all directions from the point of first movement. If now a solid but flexible body covers the liquid surface, this, too, will share in the motion more or less, according to its liability to stretch or bend. In enclosed masses of liquid, any pressure exerted on them may be sent on through them to very great distances, with scarcely diminished force, and with astonishing speed; but, especially in cases where the resistance from above is small compared to the force applied, the shock immediately makes itself felt at the surface. You will now understand why an earthquake is perceived almost at the same moment over a wide extent of country. The energy of the powers let loose in the depths of the earth must be the more destructive, as you will at once see, the less the thickness of the solid crust beneath which they are at work. The peculiar violence of earthquakes in all volcanic districts, as well as the volcanic activity itself, bears witness to a quicker increase in such places, from the surface downwards, of the inner heat of the earth.

Since, by reason of the gradual cooling of the surface of the earth from its original state of red heat, its solid crust must formerly have been everywhere thinner than it is now, we may conclude that volcanic actions and shocks must have been far more extensive and frequent in ancient ages than at present; and, in fact, we find in every country the clearest proofs of volcanic power having been once at work. It has been generally proved by the researches of geologists that the masses of trachyte and basalt, which are so widely spread over the earth, and so nearly related in all their chemical features to volcanic lava, are, wherever they occur, volcanic products. These rocks have in some places flowed forth just like lava, in others have been heaved up in cones; they have broken through masses of other strata, and have often been forced, while yet liquid, into all their clefts and crevices.

We may indeed, with a probability which almost amounts to certainty, consider all the great mountain-chains of our earth as volcanic upheavals. Not only do the numerous remains of sea-animals, which we often find on the highest crests of mountains, and of which almost whole strata are made up, lead to this conclusion, but the whole formation and condition of the rocks themselves give unanswerable witness to the fact. Besides, there are plenty of instances of mighty upheavals of land within historical times, and even in modern days. Between the islands of Santorin and Therasia, in the Grecian Archipelago, both of which, as VON BUCH has shown, bear the stamp of craters of upheaval, several little islands have risen up, the last in the year 1707, and generally with the accompaniment of violent volcanic outbursts. The Monte Nuovo, which I have already mentioned, started up in 1530. In the year 1759, the crater-cone of Jorullo rose suddenly, in the midst of a violent discharge of steam and ashes, in one day, fourteen hundred feet above the surface, on a large plain on the west of Mexico, many square miles in extent, and up to that time rich and fruitful. In May, 1796, the volcanic island Joanna Bogosslowa rose between the isles of Umnack and Unalaschka, which belong to the Aleutian group; and it is smoking to this day. Not far from the island of St. Miguel, one of the Azores, small islands have several times started up, but they have soon sunk down again. On the 31st of January, 1811, the large island of Sabrino appeared there, but only for a short time. Lastly, only a few years ago, in 1831, the little island Ferdinandea rose off the south of Sicily, but was soon destroyed by the waves of the sea.

Permanent upheavals, of large extents of country, resulting from earthquakes, have several times been observed along the coast of Chili; for instance, in the years 1822 and 1835.

In Sweden, a gradual rise of the northern coast has been remarked for many years, while the southern end of the peninsula seems to have been going down. Sinkings, and even alternate sinkings and risings, of the same tract of country have likewise been often observed; for instance, on many parts of the Italian coast, especially in Calabria. However, upraisings of the land seem generally to occur most frequently.* If we connect with these and similar facts, the existence of lofty and vast mountain-tracts, which, according to the judgments of geologists, can only have been formed by settlements from water, it will seem to be certain, that a far greater portion of the earth must once have been covered with water, than is so now; and that our present continents must have been gradually raised out of the sea, in part by these settlements† from its waters, in part by matter brought down by floods, and in part especially by the action of the elastic powers within the earth.

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* The earthquake mentioned in the Biblical history, by which Sodom and Gomorrha were destroyed, seems to have caused a sinking in of a great part of the bed of the Jordan, and of the country which now surrounds the Dead Sea; for this lake now lies more than a thousand feet below the level of the Mediterranean and of the Red Sea, while geological researches make it very probable that the Jordan formerly ran into the Red Sea.

† You will of course remember the wonderful agency of the coral insects, by whose industrious work islands are still being built up in the great ocean.

A general view will now convince you that the phenomena of burning mountains and earthquakes, and the discharges of gases and steam, as well as hot springs, are but the last remaining tokens of those mighty natural forces, which in the first ages rocked our earth in its cradle,—by which, through a long succession of struggles and revolutions, during periods of time that the measure of history cannot span, its surface was wrought into its present form, —by which the sea was divided from the land, the highlands and mountains raised up, and the valleys brought low, the courses planned for the rivers, and the beds prepared for the lakes.

But even these last traces of still active underground power must by degrees dwindle away. Great quantities of heat, as you have seen, are every year withdrawn from the bowels of the earth by the hot springs, the steam-jets, and the lava-streams; though all this, it is true, is but a small fraction of the immeasurable stores which still remain behind. But these losses are not repaid; and all the losses are added together in the course of years. Besides this, it is likely that, by the gradual cooling of the earth, even more is lost than by the means which I have mentioned. And even if the outermost crust of the earth be an exceedingly bad conductor, and if it do receive daily from the sun a great quantity of heat, both of these influences together can only retard, not altogether stop, the gradual escape of the inner heat, and its dissipation into space. For according to the laws which are received as the true expressions of the movements of heat, a spherical body, which has a higher temperature within than at its surface, and which is surrounded, as the earth is, by the sun and the starry heavens,—by sources of heat, by whose mean effect temperature as high as that of its mass within cannot be produced at the surface,—must at length be cooled down to the mean temperature of the surrounding space.

A time must therefore come when fiery mountains shall no longer, on the one hand, stand in awful contrast in the midst of the realms of ice, nor on the other hand, with the earthquake's aid, ravage lands the most fruitful and flourishing, nor lay the hopes and labours of men in ruins, in a moment, for years, or for ever. And the jets of steam, and the hot springs, must at last lose their power, with their heat; and every spring must one day flow with cold water only. This time must indeed be far, very far off, since the temperature of the earth does not seem to have undergone any change during two thousand years. Many volcanoes, of which history records the activity, seem, it is true, to have become extinct already; but many other new ones have arisen. Regions, the volcanic nature of which was known to the ancients—such as Syria, the Greek Islands, and Southern Italy—are to this day often visited by earthquakes and outbursts. The activity of Vesuvius seems not to have diminished since its first outbreak in the time of the Emperor Titus. Many hot springs which were used by the ancients, are still in repute.

A calculation made by La Place gives a very remarkable proof of the extremely slow cooling of the inner mass of the earth. From certain observations of the Alexandrian astronomer Hipparchus, the details of which have come down to us, the period of the daily revolution of the earth on its axis—that is, the length of the sidereal day at that time (150 B.C.)—may be determined with accuracy. If, now, the mean temperature of the earth's mass had diminished 1° Cent. ($1\frac{4}{5}$° Fahr.), this must have contracted proportionally, and its diameter and circumference must have become less. If, then, the speed of the revolution of all its parts remains unchanged, the time of its revolution must have become shorter. If the mean density of the earth were not greater than that of glass, the sidereal day would, as La Place shows, have become shortened by two seconds. But the actual change which has taken place since the time of Hipparchus does not amount to the hundredth part of a second.

Besides, however much the temperature within the earth may still be lowered, the condition of its outer shell, with respect to heat, cannot be much changed thereby; because the escape of heat from within, compared with that which comes to it from the sun, amounts at present, by reason of the very slight conducting power of the earth, to almost nothing.

LETTER VIII.

ON THE TEMPERATURE OF THE OUTERMOST CRUST OF THE EARTH.

Nearly all the heat, that is in the surface of the earth, comes to it from the sun, reaching our planet by radiation. The heat-rays have the property of imparting warmth only to such bodies as can arrest their motion, or, as we say, absorb them. The air is not a substance of this kind, but, on the contrary, gives free passage to the greatest part of the heat-rays, without deriving warmth from them, just as it is traversed by the light; and thus it is that, although, in their path to the earth, the rays of the sun must pass through the atmosphere, yet they do not part with any considerable portion of their heat, until they arrive on the solid surface. The exact analysis of this behaviour is one of the most interesting tasks of experimental physics; but the simple fact can scarcely escape even an unpractised observer. I need only remind you of the impression you receive on passing suddenly from the shade into bright sunshine, on removing a screen from between your face and a glowing fire, or on coming suddenly upon a close view of a smith's forge. You know that in all such cases the sensible effect is so instantaneous, as to leave no room for supposing that the air—one of the worst conductors of heat—can have the slightest share in producing it.

However the heating rays of the sun cannot pass down to the surface of the earth, without their power being weakened. A part always remains behind in the air. This portion, which in perfectly clear air is inconsiderable, increases when the atmosphere is obscured by mists, and may even amount, when the heavens are overcast with thick clouds, to the whole of the heat flowing in from the sun. The heat thus absorbed by the clouds contributes nevertheless but slightly, or not at all, towards raising the temperature of the air, since it is chiefly employed in re-converting these mists, which consist of the precipitated moisture of the air, into invisible vapour; and thus this warmth passes into the state of combined heat, which is imperceptible by the thermometer.

A second loss incurred by the heat on its way to the earth, depends upon the gradually increasing density of the air from above downwards; for the sun's rays, on passing from a rarer to a denser medium, suffer a refraction, which, as we learn from experiment, is always attended by a partial reflection. By these continual reflections, the solar rays must, in their descent through the denser and denser strata of the atmosphere, be deprived of great part of their lighting, as well as of their heating power. Experiment, so far as it has been possible, has distinctly proved the fact, in reference to this behaviour, that the sun's rays (equal surfaces being supposed to be offered to their vertical influence) have a greater heating power on mountains than in valleys. In the Alps, for instance, they lost, in perfectly clear weather, during their passage through an atmospheric depth of six thousand feet, one-fifth of their heating power. The experiments were made on Faulhorn, simultaneously above and below. (FORBES.)

The atmosphere in the different regions of the earth is by no means, even on the brightest days, equally free from mists, which, as I have explained, appropriate some of the heat. Thus the sun's rays in England, at the level of the sea, manifest only three-fifths of the heating power, which they possess at the Cape of Good Hope. In general, the nearer you approach to the equator, travelling from the poles, the clearer will you find the air, and therefore the more pervious to the sun's rays. As a rule it may be said, that, in the same latitudes, we number more bright days, and enjoy a clearer air, towards the interior of the continents than in the neighbourhood of the sea-coast.

The parts of the sun's rays which, after these subtractions that they suffer in the atmosphere, succeed in reaching the surface of the earth, exert a warming influence, which is very unequal, varying according to the direction in which they arrive (their incidence). Every one knows how feeble is the effect of the morning and of the evening sun, compared with that of noon-day; and every one is aware that the heat of our summer is intimately connected with the height, which the sun attains above the horizon. Yet the inferior effect, of these slanting rays, depends in but a very small degree on their passing through thicker layers of an atmosphere, which is usually more charged with mists.

To obtain a clear insight into the cause of this peculiarity, conceive a stream of water into which you plunge a plank, at various inclinations successively, but always to an equal depth, so that it is always struck by an equal quantity of the running liquid.

You will immediately understand that the immersed portion of the plank will be the smaller, the more nearly the direction in which it encounters the current approaches the perpendicular. Just so, then, do the rays of the sun form a stream flowing towards the earth; beams of them, equal in section, strike *smaller* surfaces on the earth, and therefore exert a greater heating influence on *equal* surfaces, the more perpendicularly they fall. This explains why the power of the sun at any place is less, the greater its distance from the equator, and how the southward slopes of mountains receive the most heat in our latitudes.

The earth-surface, thus warmed by the sun's influence, yields up again, by radiation, and by conduction to the cooler matter in its neighbourhood, a portion of the heat which it receives. One part of the heat derived from the sun is thus transferred to the underlying strata of the earth, another part is taken up from the ground by the air that rests upon it. Of the rays, which the heated earth sends forth, and which have now again to pass through the atmosphere, there also remains behind a portion sometimes greater, sometimes less; the rest diffuses itself into space, and is lost for any purpose of terrestrial heat.

We receive heat most copiously at noon, when the sky is cloudless. However, this point of time is not that of highest temperature on the earth's surface. For this latter, while it is taking in heat, is always parting with it at the same time; so that the temperature must continue to rise, so long as the influx of heat exceeds the escape; and thus the limit of increase of temperature must coincide with the point of equilibrium of these two antagonist actions. Now there is scarcely any difference between the direction and, consequently, between the heating power, of the rays of the sun when it is at the highest point, and that which it has for some time after; but the excess of influx of heat is greatest precisely at this time. The temperature of the earth must therefore continue to rise for some time after mid-day, or, in other words, the greatest diurnal warmth is always some time after noon,—in summer about three o'clock, in winter about one P.M. For a short time now the receipt and expenditure of heat are equal; then the latter preponderates, and cooling begins, at first slowly, since a part of the loss is continually restored by the presence of the sun, more quickly after sunset. All night through the temperature falls, and even some time after the sun is up, for the first influence of the early morning sun is not sufficient to counterbalance the loss of heat that is still going on. At last the equilibrium is attained, about half an hour after sunrise. This is the point of lowest temperature.

The lower strata of the earth's crust, sharing as they do in the heat received by the surface, must in turn, from the store they have before acquired, pay back in temperature to it when the cooling of the latter is proceeding. For this reason the cooling process goes on more slowly than, without this agency, would be the case.

In every place on the earth, where the lengths of the day and night are subject to but slight variation during the course of the year, these alternations of the temperature of the ground must be repeated from day to day in nearly the same manner.

This is true of all districts lying near the equator. In higher latitudes, a distinction between the seasons becomes in general the more distinctly marked, the greater the difference between the longest and shortest days in the year. As the length of the day increases, the maximum of daily cooling of the ground diminishes; the cause of heat increases in strength. The daily maximum of heating now advances from day to day. About the time of the longest day the excess, of the influx of heat above the escape, is at its greatest. Yet this point of time does not coincide exactly with that of the greatest annual income of heat, since the shortening of the day is, for some time after the 21st of June, scarcely perceptible. The daily gain in heat still continues to exceed the loss, and it is not before the end of July that the one effect is quite balanced by the other. This then is the period of greatest annual heat, at least in the temperate zone of the earth. In August the excess of cooling is still scarcely perceptible, but it is becoming more and more apparent in the following months, till at last at the shortest day, the diurnal loss of heat has reached its maximum. The lowest temperature of the year, however, does not occur till later, because for some time after the 21st of December the daily loss of heat exceeds the quantity received. Thus it is that the coldest days of the year fall on the average about the middle of January.

In the higher latitudes the proportional diminution of the heating power of the sun is compensated, to a great extent during the summer months, by its longer stay above the horizon; and thus, not only in the temperate zones, but even within the polar circle, a warm though brief summer is ensured.

The three months, June, July, and August, correspond pretty nearly with the summer in the whole of the northern hemisphere, and with the winter in the southern. During our autumnal months, September, October, November, spring reigns in the southern hemisphere. The season that is coldest on the average, or the winter, of the north, falls in the months December, January, and February, which are the summer months of the south. Lastly, the spring of the one-half of the globe, and the autumn of the other, are represented by the months March, April, and May.

The preceding considerations will give you but a very general notion of the conditions of climate at different points of the earth's surface, since these conditions are everywhere, and especially in the extra-tropical regions, modified by local causes, and by variations in the state of the atmosphere. The true relations of the temperature of one district cannot therefore be deduced from those of another, by simple reference to the position of the sun, and in general can only be ascertained with certainty by actual observation.

Suppose that, at any given place, the total amount of heat received in a year was equally distributed over equal intervals of time, so that, for instance, in one hour exactly as much heat was taken in as during another hour, then the number thus obtained would be the expression of the *Mean Temperature of the Ground* at that place. This may be determined approximately by placing the end of a correct thermometer an inch deep in the ground, so that the bulb at least should be covered with earth, in a dry, shaded spot. Now let the position of the mercury be noted after equal successive intervals of time—for instance, hour by hour—and take the arithmetic mean of all the observations. This mean-value deduced from the observations of a day, of a month, of a season, and lastly of a whole year, gives the mean temperature of the day, the month, the season, the year. You will find that the mean yearly temperature of a place is subject, from year to year, to but very slight variations, which moreover in the course of years will perfectly compensate each other. The total annual income of heat is therefore equal to the outgoings. Were this not the case, the annual mean must either increase or diminish in the lapse of years.

It is evident that places of equal mean temperature must, on the average, receive equal quantities of heat, and that any district will be the more powerfully heated the higher the value of its mean temperature. These mean numbers, however, taken alone, by no means indicate the proportions of heat taken in at different places, since we must know, besides this, the temperature of the surrounding space, or the degree of heat from which the warming effect of the sun's rays commences, and below which the surface of the earth could not be cooled even during total absence of the sun.

I have already reminded you that the sun is not the only heavenly body from which the earth derives warmth. The fixed stars make some, though but very small, contributions. If the sun were not there, the earth would be cooled down, until the continual escape was in equilibrium with the ingress of heat from the starry heavens. You will see that there would result a certain degree of heat, equally distributed over all parts of the earth; this is what we call the *Temperature of Space*. FOURIER, who was the first to call attention to the lowest possible depression, towards this extreme limit, of the temperature of any spot on the earth, believed that —45° Centigrade (49° below zero, on Fahrenheit's scale) should be taken for this point. But since his time, degrees of cold considerably lower than this have been observed in the open air. The mean temperature of space must therefore be lower, and cannot possibly be higher than the lowest observed temperature—namely, −60° C. (76° below zero, Fahr.)

Let therefore −60° be assumed to be this point, and let the mean temperatures of three different places on the earth be 0°, 10°, and 20° (Centigrade), then the numbers, 60, 70, 80 express the proportions of the mean yearly influx of heat into the ground at these three places; we shall soon see that the whole of this heating effect is not due merely to the immediate influence of the sun.

I have previously mentioned that the variations of temperature, at the surface of the earth, extend to a certain depth in the ground. Hence there must be perceptible daily, monthly, and yearly, highest and lowest temperatures of the parts below as well as of those upon the surface, the differences of which limits for the former are dependent on those of the latter.

The daily oscillations of the external temperature are, by reason of the slight conductivity of the ground, perceptible only at very moderate depths. The highest temperature of the day is already past before the surface-soil has had time to transmit its heat to the strata below, and this inward progress of the heat is still going on, when the surface has already again begun to cool.

For the same reason, the inner strata lose but very slowly the heat which has once been imparted to them; and the temperature of the outer layers is already on the rise, before the cooling can have reached to any depth, but while it is still going on within. Thus the daily variations of temperature, especially all rapid and irregular changes, are scarcely perceptible at a few inches below the surface, and are soon entirely lost as the depth increases. However, the condition of the soil is certainly not without influence in modifying these processes. Thus, in dense and solid rocks, the heat is usually conducted somewhat more quickly than in light spongy soils; in the latter, on the other hand, the rain-water, and with it its temperature, can penetrate to greater depths.

The effect of the daily variations reaches in Central Europe, on an average, to a depth of about one foot and a half; at the depth of three feet they are no more perceptible,—that is, prolonged alterations of the external temperature are only felt at this depth after several days. At four or five feet below the surface such changes only take effect, as occur from week to week, and still deeper, only those from month to month; till at last we reach the limits at which the temperature is invariable from year to year.

The experiments which have hitherto been undertaken for the purpose of ascertaining this limit at different places with any accuracy, are far from numerous; however, from these few, so far as they are known, we learn most distinctly that the influences of summer and winter are more and more retarded as the depth increases, and that the monthly and yearly oscillations converge more and more to a certain mean result.

Thus Quetelet obtained at Brussels, from observations made during several years, at the same time of day—namely, at noon—the following mean values:—

Depth in Parisian feet.	Annual Mean in Degrees of		Excess of the Maximum over the Minimum of the Year.		Date of occurrence of the			
	Centigrade Scale.	Fahrenheit Scale.	Centigrade Scale.	Fahrenheit Scale.	Maximum.		Minimum.	
						d. h.		h. d.
0	9·90	49·48			July	22	Jan.	22 9
0·58	9·71	49·82	13·89	25	„	26 8	Feb.	2 9
1·38	10·07	50·15	12·82	23·07	„	31 1	„	11 ·4
2·31	10·31	50·56	12·06	21·71	Aug.	5 4	„	21 8
3·08	11·16	52·09	10·44	18·79	„	8 3	„	24 8
12·00	11·99	53·58	4·61	8·29	Oct.	12 5	April	21 7
24·00	11·88	53·38	1·48	2·46	Dec.	12 0	June	18 5

In the first of the above columns you will find the depth at which the thermometer was placed below the surface; in the second, the mean temperature of the year at these several depths; the third shows the respective differences of the highest and lowest temperature of the year; and the fourth the point of annual time at which the highest and lowest temperatures respectively were reached, at the different depths.

The following sets of observations, of which the first was made in mid-winter, the second in the middle of summer, are borrowed from a very extensive series made by G. Bischof.

Depth in Parisian feet.	Thermometric Degrees observed on			
	July 18, 1836.		January 21, 1837.	
	Centigrade.	Fahrenheit.	Centigrade.	Fahrenheit.
6	16·12	60·99	4·81	40·75
12	12·06	53·6	7·81	46
18	10	50	9·94	49·9
24	9·5	49	10·95	51·79
30	9·62	49·1	10·88	51·58
36	10·2	50·5	10·88	51·58

According to these results, the influence of the summer-heat is not felt, at a depth of 30 feet, before the winter of the following year, nor the influence of the winter-cold before the next summer.

Bischof found the mean temperature of the year, at Bonn, to be as below :—

Depth in Parisian feet.	Thermometric Degrees.			
	Annual Mean.		Difference between Highest and Lowest Temperatures.	
	Centigrade.	Fahrenheit.	Centigrade.	Fahrenheit.
6	9·7	49·3	12·38	22·38
12	9·8	49·5	8·13	14·63
18	10	50	4·88	8·78
24	10·2	50·5	2·75	4·95
30	10·4	50·7	1·44	2·59
36	10·6	51	0·81	1·45

The dates of occurrence of the mean values of the maxima and of the minima were :—

Depth in Parisian feet.	Annual Mean.	Maximum.	Minimum.
0	April 24 and Oct. 21	July 26	Jan. 14
6	May 20 „ Nov. 11	Aug. 11—20	Feb. 11—20
12	June 19 „ Dec. 18	Sept. 18—19	March 18—19
18	July 19 „ Jan. 18	Oct. 18—19	April 18—19
24	Aug. 15 „ Feb. 18	Nov. 15—18	May 15—18
30	Sept. 13 „ Mar. 18	Dec. 13—18	June 13—18
36	Oct. 11 „ April 7	Jan. 7—11	July 7—11

Bischof states that the annual variations of temperature do not vanish completely within the depth of 60 feet. Quetelet arrived at the same result by his observations made at Brussels. But the temperature observed at such a depth as this does not correspond to the mean at the surface, but is raised by the influence of the internal heat of the earth, which, as may be deduced from the yearly mean-numbers above quoted, is already perceptible at but little distance from the surface. For this reason we must not reckon, as true expressions of the heating due to the solar rays, any indications of temperature by thermometers placed more than about six feet below the surface.

The knowledge of all these facts leads us now to the following simple method of determining the mean temperature of the earth's surface at any given place. Let a thermometer, with a sufficiently long stem, have its bulb sunk between 3 and 6 feet deep in the earth, so that the graduated scale projects above the ground, and that consequently the oscillations of the column of mercury may be observed without withdrawing the instrument. One observation in the day is then perfectly sufficient, since all accidental external variations, and even the regular ones during the day disappear at this depth. Indeed, it appears that at a depth of 6 feet, four observations during the month are sufficient to enable you to deduce the true mean for the month, and, from twelve such monthly data, the mean of the year.

We may obtain information concerning the temperature of the ground at any place by examining the springs, but our results are less certain, unless we are perfectly sure that the springs have their sources at very moderate depths. Springs, which rise from a depth of 30 feet or more, give, as you will readily understand, too high a temperature; and that this is the case with them you may infer with the greater likelihood of truth, the less are the variations to which they are subject in the course of the year. Springs of an invariable, or nearly invariable temperature, have their origin undoubtedly at considerable depths, and are allied in their nature to hot wells.

Bischof recommends us to examine, if possible, once or twice a month during a year, the temperature of more than one spring in the same neighbourhood; adding that the annual mean of the coldest will approximate closely to the true mean temperature of the ground in the locality.

Shallow wells which are in constant use, being fed by the land-springs filtered from the surface soil, or deriving their supplies from neighbouring rivers or brooks, have a temperature varying with the seasons, or even from week to week, so that their annual mean cannot differ very far from that of the ground.

LETTER IX.

ON THE TEMPERATURE OF THE LOWEST STRATUM OF THE ATMOSPHERE.

The mean temperature of the lowest stratum of air that rests on the ground is generally the same as that of the soil, however great the variations may be, which you observe from time to time. It was formerly believed that this agreement occurred only in temperate latitudes, and that in the torrid zone the temperature of the ground was lower, and, on the other hand, that towards the polar circles, and beyond them it was higher than that of the air. This assumption was grounded on observations which had been made on springs. But the inference has lost its force since we learned that springs frequently receive their supplies in great part from considerable distances, thus bringing heat from the depths below, and cold from the high lands above. It must then at present be considered as certain, that there is this relation between the temperatures of the air and of the soil, that their yearly mean values are the same.

The direct determination of the mean temperature of the air is attended with greater difficulties than of the ground. The cause of this lies in the slight density of the air, and in the increased effect which this gives to any heat-influences acting simultaneously with the sun upon the thermometer.

A thermometer of extreme accuracy, but rather sluggish in its movements, should be suspended in the shade, if possible on the north side of a building, at a distance of one foot from the wall; and its position should always be such that it is neither exposed directly or indirectly to the sun's rays, that it should not be wetted by rain, and that it may be cooled as little as possible by nocturnal radiation. The wind, however hard it may blow, should have no effect at the point where the instrument is placed. If the index of a thermometer exposed to the wind stands at any given time lower than that of another, which is protected from its influence, it is evident that there are certain foreign heating agencies which are not perfectly shut out from the latter.

To determine with accuracy the course of the temperature in the course of the day, observations should be made at least every hour, *i. e.* twenty-four times a day.

The numbers of the hours are usually pointed off on a horizontal straight line (for the abscissæ), dividing it into equal parts, and the corresponding degrees of the thermometer are marked on straight lines drawn at right angles to the former at these points, and likewise divided into equal parts (for the ordinates). By this mode, twenty-four points are obtained, which, when connected by a continuous line, give a very clear graphic representation of the daily range, enabling you to ascertain by simple inspection the time of occurrence of the daily maximum and minimum, as well as two daily mean values.—In central Europe, the lowest temperature of the day, taking one day with another, is generally found a little before sunrise; the highest in summer about three o'clock, and in winter between one and two in the afternoon. Of the mean temperatures, one falls between eight and nine in the evening, and the other between eight and ten in the morning.

The curved line which represents the course of the temperature encloses with its abscissæ and ordinates a number of small figures, of which the sum is equal to a rectangle, whose base is the abscissa representing the length of the day, and whose height is the arithmetic mean of the twenty-four ordinates. This shows the correctness of the process, which is universally adopted, of deducing the mean diurnal temperature of the day, from the arithmetic mean of the observations made at equal intervals during the day. From this, too, it is evident that this process can only give correct results, when the observations have been made in number sufficient to give the true form of the curve.

Since it is very laborious to continue so great a number of observations through a long period, methods have been contrived which render it sufficient to note the state of the thermometer but a few times in the day. Experience has led us to several aids of this kind, of which, indeed, none serves with certainty for the determination of the mean temperature of a *single* day; but several of them, when the object is to find the mean of longer periods of time, are extremely useful, and among these the following are the best.

Humboldt first remarked that the sum of the highest and lowest temperatures in the day, divided by two, gives almost exactly the true diurnal mean. Thus, by the use of a good registering thermometer, the mean temperature of each day may be readily determined.

A second method consists in reading off the height of the thermometer at any three or four points of time, chosen at equal intervals: for instance, at eight o'clock in the morning, at four in the afternoon, and at midnight, or at four and ten in the morning, and at four and ten in the evening, and then from these three or four observations respectively to deduce the mean.*

If the object be only to obtain from the daily means that of the month or of the year, you can get a good approximation to these, from the temperatures daily observed at any two hours of the same name, especially at ten or at four o'clock, morning and evening.

By means of comparisons made during several years at various places in the temperate zone, it has been found that the thermometer generally stands at its lowest in the middle of January, and that from that time it mounts, slowly at first, more quickly in April and May, then more slowly again, till by the end of July it reaches its highest mark. Then begins its descent, which being slow at first, is hastened during September and October, and lasts, becoming slower again, to January.

According to KAEMTZ, the 14th of January is, on the average, the coldest, and the 26th of July the warmest day in the year, while the mean temperature of the year falls about the 24th of April, and the 21st of October.

The mean temperature of the surface of the earth, and of the lowest stratum of air that rests immediately upon it, varies between the limits −18 C and +29 (0° and 84° Fahr.) It diminishes generally, as of course you are aware, as the latitude increases.

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* This process would probably yield even more satisfactory results, if a thermometer was employed, the movements of which were retarded by clothing it with a nonconducting envelope.

If we consider the quantity of heat that falls vertically on the equatorial regions of the earth, and the heat thus conferred upon the ground, over and above the temperature of space,—if we consider these as given, then the immediate influence of the sun's heat may be found by calculation from the altitude of the sun, in higher latitudes. According to this calculation, even assuming the temperature of space as not lower than − 60° Centigrade (*i. e.*, − 76 Fahr.) the mean temperature of the year—at, for instance, the 50th degree of latitude—would still be considerably below 0°, while, however, in reality under this parallel in Germany, it is very nearly as high as + 10° C. (+50 Fahr.) Under the arctic circle, the annual mean could not rise above − 50° C. (− 60 Fahr.); and yet, hitherto, nowhere on the earth has a temperature lower than − 56°·7 C. (−70 Fahr.), and that only transiently, been observed. From this we learn that the warmth of the earth in higher latitudes must be far from being dependent exclusively on the immediate influence of the sun. In fact there are many conditions and processes going on upon the surface of the earth, by the collective effect of which a great part of the heat of the torrid zone is dispersed over the colder regions of our earth, so that the heat of the former, and the cold of the latter, are mutually mitigated. The most universal of these causes are the peculiar distribution of the land and sea, the direction and height of the mountain-chains, the currents of the ocean and of the air, and evaporation.

Since these various agencies towards the distribution and equalization of temperature over the surface of the earth (to which are added numerous local influences, and even many which are altered in the lapse of time) are often of very dissimilar importance under similar latitudes, it thus happens that the places of equal annual temperature, lie in latitudes frequently ten degrees apart.

HUMBOLDT was the first to draw attention to these remarkable relations of temperature, by connecting the places of equal annual temperature by lines drawn round the earth, which he called *Isotherms.* The number of points—for which, up to the present time, the mean temperature of the year has been determined—are too few to enable us to gird the globe with a perfect system of isotherms. However a sufficient number of observations have been collected, at least for the northern hemisphere, into which the greatest masses of land are compressed, to indicate the main directions of these lines. The isothermal charts, which have been designed from these,* exhibit at one glance the great divergence of the lines of equal mean temperature from the parallels of latitude. I subjoin some instances, by following which, on a good map of the world, you will obtain a tolerably clear view of this remarkable relation.

The isotherm of 20° Cent. (68 Fahr.) cuts the west coast of Africa to the south of Mogador, it then rises towards the Mediterranean Sea, passes to the south of Algiers (19°·6 C.), runs along the coast of Tunis (20°·3), to Cape Bon, then running to the south of Sicily, Candia, and Cyprus, crossing Syria between Damascus and Jerusalem, and rising gradually towards the north, it passes south of the Caspian Sea at Teheran, and over the table-land of Iran, verging southwards till it falls on the eastern coast of China, in the latitude of the Loo-Choo Islands. It reaches the peninsula of California, 28° N, and it then soon turns again more towards the north, and runs along the 32nd parallel through Texas, Louisiana, Mississippi, Alabama, and Georgia (Savannah, 19°·5) to the Atlantic; hence to the Bermudas, passing slightly to the south of Madeira (at Funchal, in Madeira, 19°·8, at St. Cruz, in Teneriffe, 21°·6), to the African coast.

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* These may be seen in the "Physical Atlas" of BERGHAUS, or in the English edition, by JOHNSTON and others, or in DOVE's well-known charts.

The isotherm of 10° Cent. (50 Fahr.) runs through the south of Ireland (at Dublin 9°·6, Cork 10°·6), through Wales (being at Liverpool 9°·6, at Plymouth 11°, Penzance 11°·1), towards the south of England, near London (9°·8), leaving France (Paris 10°·5) and Belgium (Brussels 10°·5) on the south, through the Netherlands (Haarlem 10°, Amsterdam 9°·8, Franeeker 10°·3), it bends suddenly at the German frontier to the south, west of Münster (9°·5), Düsseldorf (9°·5), Elberfeld (9°·1), Treves (9°·8), Metz (10°·3), and Frankfort (9°·8); to Mannheim (10°), Carlsruhe (10°), Heidelberg (10°); it then continues in an easterly direction, touching Würzburg(10°), through the south of Bohemia and Moravia (Prague 9°·6, Olmütz 9°·1, Vienna 10°·5), the north of Hungary (Ofen 10°·5, Klausenburg 10°·4) through Moldavia, and to the south of Odessa (9°·1), through the Black Sea; it cuts the north part of the Caspian Sea (Astrachan 9°·4), and probably passes to the north of the peninsula of Corea under the 42nd parallel, on the eastern coast of Asia. It strikes the west coast of America at the mouth of the river Columbia, at north latitude 46°, but descends again, as it proceeds eastward to the 41st degree, touching Council-Bluffs (10°), on the river Platte, Detroit (10°·1), in Michigan, North Salem (10°·1), in New York, and then runs a little to the south of Boston (9°·6) to the Atlantic, from which, during its course to Europe, it turns quickly up to the 51st degree N. L.

The isotherm of 0° C. (32° Fahr.) follows the north coast of Iceland and the Arctic Circle; it touches the North Cape (0°·1), on the continent of Europe, under latitude 71° N; from this point it turns suddenly to the south-west, running along the chain of mountains that separate Sweden from Norway (Alten 0°, Enontekis, in Russian Lapland, – 2°·7). It then, bending first towards the south-east, returns to the Arctic Circle, touches Tornea, leaves Uleaborg (0°·7), in Finland, on the south, descends, towards the interior of Russia, (Petersburg 4°, Moscow 3°·9, Casan 2°·2), more and more to the south, almost touching Slatoust (0°·3), under the latitude of Moscow and Casan. It then, leaving Ekaterineburg (0°·5) and Petropablousk (1°·9) on its south, and Tobolsk (–2°·4) far on its north, passes more nearly parallel with the lines of latitude on the north of Barnaul (1°·8), and near to Irkutsk (–0°·2), then bends again towards the sea, cuts through the middle of Kamschatka, and seems to reach again to the Polar Circle on the north west of America. In the interior of this continent, however, it again runs rapidly southwards, following the course of the northern Rocky Mountains, touching Lake Winnipeg (Cumberland House Factory 0°), and cuts the southernmost sweep of Hudson's Bay. From the eastern coast of Labrador it stretches northwards again, and without reaching the southern point of Greenland (Julianshaab, 0°·9) returns to Iceland.

If you follow the course of these lines of temperature with your eye on a map of the World, you will remark, that the belt of land enclosed between the isotherms of 20° and 0° (68° and 38° Fahr.), the true temperate zone of the northern hemisphere, bends farthest towards the north in Europe, and here also has its greatest breadth, since it contains not only the European continent, but also all the islands lying between the parallels of 35° and 71° N. L., and even a part of the north coast of Africa, a breadth altogether of 36° of latitude. However, at the extreme east of Europe, and much more strikingly in Asia, its limits are contracted, and it shrinks at its narrowest measurement in the interior of Asia to a breadth of 20° of latitude. At the west coast of North America, it encloses so much as lies between 28°, and perhaps 66° N. L. of the small strip of coast land, formed by the western declivity of the high mountains which run nearly parallel with the sea coast, but towards the interior it soon contracts again to a breadth of about 23 degrees latitude, which it retains till it reaches the eastern coast of the new continent.

While the mean temperature of 0° reaches in Europe up to 71° N. L., and on the west coast of America up to 66° N. L., in the interior of the great continents, and on the eastern coasts, it does not pass the limit of 55° N. L. The neighbourhood of the sea has, therefore, an unmistakeable influence in moderating the temperature on the western sea-borders, which it does not exert on the eastern coasts. This action is gradually weakened towards the interior of the continent, and is strikingly diminished where the high mountains, ranging north and south, separate the coast lands from the interor.

In all places on the earth through which the isotherm of 0° passes, there cannot prevail, at the underground limits of constant heat, a higher temperature than is represented by as many degrees above 0° as are due to the action of terrestrial heat. If, for instance, you were to meet at a depth of one hundred feet, with the limit I have mentioned, you would probably find there a constant temperature of about 1° C. (33°·8 Fahr.) Farther northwards, where the mean temperature of the ground falls below 0°, there must, therefore, occur a constant temperature of 0°, or even below 0° (32° Fahr.), at such a depth beneath the surface of the ground as is beyond the reach of the changes of external temperature; that is to say, in such latitudes there must be a certain depth, at which the ground is in a state of perpetual congelation. In northern Asia and in America, between 58° and 62° N. L., the ground is found to be frozen at the depth of fifteen or sixteen feet even in the hottest days of summer. At Bogoslousk (mean temperature 0°·6 C. = 33°·1 Fahr.) nearly under latitude 60° north, HUMBOLDT found the earth, in the middle of summer, thawed only to the depth of six feet. At Yakutsk (8°·1 C. = 46°·6 Fahr.) under 62° N. L., where in the months of July and August it is very warm, there is found nevertheless, at the depth of only three or four feet, a stratum of perpetual ice, the bottom of which, according to the experiments of SCHERGIN, a merchant of that place, was not reached at a depth of three hundred and fifty-eight Parisian feet. It may easily be conceived, remarks HUMBOLDT, how rapidly the thickness of the frozen stratum must increase from 62° to 72° N. L., from Yakutsk to the mouth of the Lena. Natural springs cannot therefore exist in these regions; and to obtain well water, it must be necessary to bore through the whole thickness of the layer of ice-bound earth.

WRANGEL found in Siberia, near the coast of the Northern Ocean, during the summer months, many lakes whose bottoms were frozen, and which therefore formed so many basins of ice filled with water, as is so frequently observed on the glaciers. These were quite devoid of fish, while other lakes in their immediate neighbourhood, which were deeper, were well stocked with them. In the latter, the bottom cannot be cooled below 0°, because in that case the whole mass of water would of necessity become solidified by degrees, which would kill the fish. Just so we find that the great deep lakes in the high latitudes of North America are full of fish.*

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* The possibility of the existence of great masses of water, which, resting in basins of ground frozen to more than a hundred feet of depth, and covered during the severest cold of winter with a coating of ice of at most ten or twelve feet in thickness, yet contain liquid water of and above the temperature of 0°, depends upon the remarkable property possessed by water, of attaining its greatest density at the temperature of 4° C. (39°·2 Fahr.), that is, of expanding, as well by being cooled below as by being heated above this temperature. The result of this property is, that, during the summer months, the water at the surface of one of these basins sinks as soon as it is warmed up to 4°, until the whole mass of water has acquired this temperature, and that it cannot then again be brought up to the top by any subsequent change of temperature at the surface. [While

For the determination of the course of isotherms, for degrees of temperature below 5° C. (41° Fahr.), we have as yet but very meagre materials. They seem, however, to indicate that the North Pole is not the coldest point of the earth, but that there are in the northern hemisphere two points of greatest cold. According to KAEMTZ, one lies in Siberia, about the promontory of Taimura, near the northernmost point of Asia, and the other to the north of Barrow's Straits, at the extremity of Baffin's Bay.

The lowest annual means which have been hitherto found, at least from observations continued for at least one year, are the following:

At Ustyansk, a small town at the mouth of the Yana, in Siberia, in the same latitude as the North Cape of Europe, −16° C. (2°·5 Fahr.)

At Winter Harbour, Melville Island, in lat. 74°·8′ N.,—18°·7 C. (1°·75 F.)

At the island of Igloolik, at the north of Hudson's Bay, in lat. 69°·3′ N.,−16°·6 C. (1°·7 F.)

While, therefore, in great deep lakes, the influence of a temperature of 4° reaches to the lowest depths, and does not permit the bottom to be cooled below that point, the winter-cold, which cannot be transmitted downwards except by conduction, can penetrate to but a slight depth.

At Port Bowen, in Prince Regent's Inlet, in latitude 73° 2′ N.,—15°·8 C. (3°·6 F.)

At Winter Island, at the north of Hudson's Bay, in latitude 66°·2′, −14° C. (6°·8 F.)

At Elizabeth Harbour, in Boothia Felix, in latitude 70° N., −15°·7 C. (3°·7 F.)

The line of highest mean annual temperature does not coincide with the equator, which it cuts at several points. The greatest part of its length, however, lies in the northern hemisphere. The highest mean temperatures reached in the torrid zone are about 27° or 29° Cent. (88°·6 or 84°·2 F.)

LETTER X.

ON THE TEMPERATURE OF THE HIGHER LAYERS OF THE AIR.

Our atmosphere is, as I have already shown you, but very little warmed by the direct action of the solar rays. But the lowest stratum of air shares the temperature of the ground: by this heat it is expanded, and becoming lighter, must mount (just as you see taking place with the smoke of a chimney, and the air surrounding a candle-flame), to the higher regions; allowing the colder and heavier air to press into the position which it leaves. These upward currents of air convey the heat of the soil to considerable heights, suffering, however, a gradual reduction of temperature. This cooling, in clear still air, is nearly proportional to the height, and for five hundred feet of elevation amounts to about 1° Cent. (1°·8 Fahr.)

These gradual depressions of the temperature of the air depend much less on an actual loss of heat, since it loses its heat by radiation extremely slowly, than on the lessening of the pressure: This latter effect is due to the increase of height, and in consequence of it the air rising up from the ground expands more and more, and in so doing must use up a part of its heat, which thus becomes combined or *latent*. For it is well known that the air, by sudden and powerful rarefaction, may be cooled even to below the freezing-point of water, as well as that, on the other hand, by sudden and powerful compression air may be rendered so hot as to ignite tinder.

The temperature of the higher strata of the atmosphere, so far as it depends on the influence of the heated soil, is, of course, subject to daily and yearly oscillations. The daily highest temperature does not occur till after the maximum on the earth's surface. While, for instance, in the summer months, this is attained on the plains about 3 P.M., KAEMTZ found it on the Rigi, at a height of five thousand feet, at 5 P.M.; SAUSSURE found it on the Col du Géant (in the Mont Blanc region) at a height of ten thousand feet at 6 P.M.; that is, at an hour when the temperature of the earth was already diminishing, and when, therefore, the upward current was also slackening. The more the surface of the earth is cooled at night, the colder does the air become that is in contact with it; but this effect can extend to but a small height, because the air that is thus cooled becomes at the same time heavier, and therefore ceases to rise.

The nightly cooling of the ground acts, therefore, but little on the higher layers of the atmosphere, and these yield up the heat, which they have once taken in, but very slowly. This shows why it is, that, although soon after sunset the temperature of the ground falls below that of the air, yet a thermometer hung up a few feet above the ground, and shielded by a screen from the nightly radiation towards the sky, being freely in contact with the surrounding air, shows in clear nights a temperature 5 or 6 degrees Cent. (9 or 11 F.), and even more, higher than another thermometer, which at the same time is lying upon the ground.

The various materials which clothe the soil, have altogether a far stronger radiating power than the air, but between them severally there are great differences. Water and plants are particularly strong radiators. At seasons of low mean temperature, and in clear nights, you will often see stagnant pools, of small extent and depth, become covered with a film of ice, the grass clothed with rime, and the young sprigs and leaves of trees nipped by frost, without the temperature of the air falling below the freezing point.

Plants are particularly liable to be frost-bitten in still nights, for, when the air is in motion, a great part of their lost heat is restored to them by the ever-renewed contact of warmer air. With this is connected the well-known fact, that plants growing on high ground, where the air is generally more disturbed than in the valleys, commonly suffer less from frost.

The low degree of heat of the higher strata of the atmosphere exerts, in consequence of the great mobility of the air, a very marked influence on mountainous districts, whose mean temperature is thus depressed below that of the plains in the same latitude. This is most strikingly shown on mountains seated on small horizontal areas and with single peaks; their mean temperature is almost entirely governed by that of the atmosphere at the same height; but in highland districts of great extent, and on table-lands, this effect of the height is also felt.

Thus we find the mean temperature of the year to be :—

		At a height of feet.	Degrees.	
			Cent.	Fahr.
	On the Brocken . .	3500	1	33·8
	At Clausthal . . .	1750	4·9	40·8
	At Göttingen . . .	480	8·3	47
	At Münster (same latitude)	190	9·5	49·1
	At Berlin (1° lat. farther N.)	110	9·1	48·4
On the table-land of Southern Germany.	Munich	1570	9·1	48·4
	Augsburg	1520	8	46·4
	Ratisbon	1030	8·6	47·5
	Tübingen	1020	8·5	47·38
	Stuttgart	760	9·8	49·6
	Karlsruhe ⎧ nearly	350	10	50
	Vienna ⎩ same lat.	500	10·5	50·9
In the Swiss Alps, at	The Hospice of St. Gothard	6450	—1	30·2
	Geneva.	1220	9·7	49·26
	Basle (1° lat. farther N.)	800	9·8	49·6
	Zürich (same lat. as Basle)	1300	8·8	47·8

On the far more extensive table-lands of Mexico and Quito, the lowering of the temperature is far less in proportion, than in the highlands of Germany.

According to Humboldt the mean temperatures are—

		At heights of feet.	Degrees.	
			Cent.	Fahr.
	Of Mexico.	6990	16·3	61·34
	At Vera Cruz (in same latitude) . .	on sea-coast	25	77
almost under equator	At Quito . . . . ,	8970	15·6	59·1
	At the Sea-coast . .		26	78·8

In Upper Peru and Bolivia we find a fruitful soil and a numerous agricultural population, at heights fully as great as those of the loftiest peaks of the Bernese Alps. The great lake of Titicaca lies twelve thousand six hundred, and the street pavement of the town of Potosi twelve thousand eight hundred feet above the sea level. On the north side of the Himalaya, on the high plains of Daba and Doompo (in lat. 31° 15′ N.), crops of wheat and barley ripen, even at the height of fourteen thousand feet (HUMBOLDT).

In determining the isothermal lines we deduct as nearly as possible the lowering of the temperature due to the height at which any place lies. We say, accordingly, that Quito lies on the isotherm of 26° Cent. (78°·8 F.); that Munich, Augsburg, Ratisbon, and other towns of the South-German table-land lie to the south of the isotherm of 10° C. (50° F.), which, as I have mentioned to you before, passes through Karlsruhe and Würzburg towards Bohemia. The mean temperature of the Swiss Alps, reduced to the level of the sea, would amount to 11°·2 C. (52°·26 F.)

You will now understand why, at certain heights above the level of the sea, even in the hottest days of summer, the temperature can never rise above 0° C. (32° F.); and why, on mountains loftier than this, the snow can never be entirely melted.

The limit of perpetual snow depends upon the mean temperature of the ground, and especially upon that of the summer months. The following table shows the height of this snow-line on some of the loftiest mountains which are well known to us:

Mountains.		Limit of Perpetual Snow in Parisian Feet.	Degrees of Latitude.	Mean Temperature, in Degrees, on the Plain, Of the Year.		Of the Summer.	
				Cent.	Fahr.	Cent.	Fahr.
In Norway	On North Coast	2200	71¼—71½ N.	+0·2	32·36	6·2	43·16
	Inland	3300	70 "	−3	26·6	11·2	52·16
	The same	5000	61 "	+4·2	40·26	16·2	68·16
The Alps		8000	45¾—16¾ "				
" Pyrenees		8400	42½—43 "	15·2	59·36	23·8	74·84
" Caucasus		10,400	42½—43⅓ "	13·8	56·85	21·6	
Ararat		13,300	39¾ "				
Himalaya	Northern Slope	15,600	30¾—31 "				
	Southern "	11,700					
The Cordilleras of Mexico		14,100	19 "	25	77	27·8	82·04
" " Quito		14,800	0 — 1½ S.	26	78·8	28·6	83·48
" " Bolivia		16,000	16 —17¾ "				
" " Chili		13,800	33 "				
" " Chiloe		5640	41 —43 "				
Terra del Fuego		3480	54 "	5·4		10	50

The height of the snow-level, depends, you see, only in general on the mean temperature of the year, and it falls lower and lower from the equatorial regions on both sides towards the poles. It seems to come down to the sea-level at the north of Spitzbergen beyond 80° N. L. At the north of Asia and America, it reaches it at considerably lower latitudes; so that the horizontal line of intersection of the snow-limit and of the earth's surface, like the isotherms, does not run parallel to the circles of latitude. In the southern hemisphere, the snow-level seems to descend to the surface of the sea sooner than in the northern, namely, between 60° and 71° S. L. In Terra del Fuego (55° S. L.) it comes down almost as low as in Norway, under the 70th degree. COOK found the creeks in the island of South Georgia, in the same latitude, bordered with shores of ice, and the land in many places covered with snow, in the middle of the summer. He also found Sandwich Land, whose latitude (60°) corresponds with that of the Shetland Isles, on the 1st of February, *i. e.* in the warmest season of the southern hemisphere, surrounded with ice, and the whole land, from the tops of the mountains to the foot of the cliffs, which form the coast, covered with snow many fathoms deep.

All those influences, which determine the mean temperature of the summer, affect the height of the perpetual snow at any place. On the Swedish side of the Scandinavian mountain-chain, the snow-limit retreats on account of the hotter summer to a greater height than on the Norwegian side, where, notwithstanding the higher annual temperature, the summer is cooler and wetter, and where consequently the fall of snow in the mountains is greater, and the thaw takes place more slowly than in Sweden. In the same manner, it is observed that the snow on the eastern slopes of the Andes of South America melts away to a considerably greater height than on the western side, where the summer, somewhat cooler by reason of the influence of the sea, cannot act so powerfully in lessening the store of snow laid up during the winter, as does the hotter and drier summer of the inland continent. It seems to be the general rule, that the snow-level descends in the neighbourhood of the sea, while, on the contrary, in the interiors of continents on great mountain-masses and tablelands, it is lifted up. Thus the unusually low position of the snow-line, in the mountains of southern Chili and Chiloe, which run near the sea, is to be attributed entirely to the influence of the moist sea-air. The mean temperature of Chiloe is 10°·5 C. (50°·9 F.) Nevertheless the summer there is so cool that, with the exception of apples and strawberries, no fruit ripens perfectly, and that sometimes, to ripen barley and corn, it is necessary to bring them in-doors. The island of Chiloe, like the adjoining continent, is covered with a thick forest which abounds in moisture; the air is seldom entirely clear. Only nine degrees of latitude to the north, in dry central Chili, where, during a long summer of seven months, no rain falls, and the sky is seldom overcast with clouds, the snow-line is raised eight thousand feet higher.

The Pyrenees and the Caucasus lie under exactly the same latitude; yet in the latter the snow-limit is found two thousand feet higher, because the greater distance of this range from the ocean, and the consequently greater dryness of the air, lessens the abundance of atmospheric precipitation during the winter months, while on the other hand it favours the thawing and evaporation in summer.

The influence of dryness and of the continental summer is shown most strikingly on the Himalaya, on whose southern slope the snow-level comes down four thousand feet lower than on the northern.

On the Alps, the snow-level descends throughout somewhat lower on the north than on the south side, because in Italy in winter and summer the air is warmer and clearer than it is in Germany, and moreover because the frequent warm south winds (the "Foen") first touch the southern slope.

Many peaks of the Alps, which rise above the common snow-level, yet become in summer quite free from snow, because they lie at a distance from the main mass of lofty mountains. Where, on the other hand, a great number of snowy mountains stand close together, the everlasting snow often comes down to a level at which, on single mountains, it would be melted away every summer.

During the winter months, the snow-line over the whole of Europe falls to the level of the sea, and finds its limits only between 30° and 35° N. L.; that is to say, south of this latitude we find no instance in which the snow remains lying on the plains.

On single shaded spots, of the mountains, and in gullies, into which the sun's rays can seldom or never penetrate, ice and snow often remain through the whole year at a considerable distance below the snow-line. In many gorges and deep valleys, which run up to the heights of everlasting snow, masses of ice are pushed down towards the lower grounds, and are carried forward by the mere continual thrust of the ice above them to regions where the general surface of snow can no longer remain unmelted. These valleys filled with ice form the Glaciers. The eternal ice of the glacier stands in a most remarkable contrast to the mountain-sides which bound them, and which in summer are perfectly snowless; many of these we find clothed with forests, and with a luxuriant growth of herbage, close up to the edge of the ice. In the Alpine chain there are many instances of glaciers which come down as low as the inhabited districts. Thus several glaciers descend into the vale of Chamouni, quite to the bottom of the valley; and the end of the lower Grindelwald glacier in the Bernese Oberland lies only three thousand feet above the sea. The end of the glacier, however, is not quite a fixed point. During a succession of cold summers it creeps forward, in warm years again it retreats. Yet these variations are inconsiderable compared with the length of the glaciers, several of which, through a distance of fifteen or twenty miles, follow the windings of the valleys, receiving branches here and there from side-valleys, and thus, viewed at a distance from the mountain-peaks, present exactly the appearance of broad rivers with their tributary streams. When close to them, however, you see mighty masses of ice seldom arranged in regular layers, but commonly cloven in every direction, and wedged one into another, set with wild bristling peaks, and deeply notched about their rugged sides. Here and there you see the surface covered with sand, heaps of earth, and blocks of stone, which, having fallen from the mountain sides, are borne onwards by the ice, and set down some at the sides, some not till they have reached the mouth of the glacier, where, piled up for thousands of years, and added to every year, they form the Moraines of the glaciers. Where there are not crevices in the mass, numberless little rivulets, fed by the melting ice, course over its surface, till either, received by hollows closed at bottom, they fill them to overflowing, or, pouring into deep clefts, they fall to the bottom of the valley, and then, flowing onwards under the glacier, and, joining with many others into a large stream, gush out again into the open air, at the lower end of the glacier. In spots where large blocks or heaps of stone lie upon the ice, it is screened from the action of the sun's rays. While, then, the thawing goes on around, there remain standing under the shelter of these coverings pillars of ice, on which the pieces of rock rest from year to year, while they grow, as it were, to considerable heights above the surface, till at length the treacherous props, fretted away by the weather, fall under their burden. Leaves and other thin organic bodies, which fall by chance upon the ice, work just the contrary effect. They have, as has long been shown experimentally, in a very far higher degree than ice, the power of turning the sun's rays into sensible heat. But since these must, if they are of small thickness, immediately send on to the ice beneath them the heat which they take up, this ice must melt more rapidly than that which surrounds it, and thus little hollows are formed, which, when once filled with water, are soon increased in depth by the liquid, which is heated at the top to above 0° C. (32° F.) and then sinks to the bottom.

Although the proper ice of the glacier holds together as a solid mass, yet it appears, on closer examination, to be quite full of cracks as fine as hairs: it has not, therefore, in the mass, the transparency of common ice, and differs from it too in being somewhat less brittle, if, as generally happens, its little cracks are soaked full of water. Farther up it takes a granular texture, and in the highest parts of the glacier you find only a mass of very fine grains, partially frozen together,—the *Firn*. The firn is formed from the snow fallen during the year, by the water thawed upon the surface, which again and again first soaks into it and then freezes. By these changing influences, which last during its downward movement, it is turned into the solid glacier-ice, which, therefore, is not marked off from the firn by any sharp boundary line.

In the firn region the ice forms horizontal layers, which probably consist of the snow-beds of each winter, and their levels are marked by the dust and sand, which are blown in the summer time by the wind from the naked walls of rock. Each layer, therefore, shows the passage of a year. As the firn reaches downward in the valleys to the proper glacier region, the layers, which are at first level, become bent; since they sink in from the two borders to the middle, and down the slope of the valley. Farther below, this bending of the middle increases; the cropping out of the several layers, (which, in general, may be readily distinguished by the somewhat different condition of their ice, and of the sand which still clings partially to the surfaces which were formerly uppermost,) falls more and more into acute angles towards the middle, and is there in some places even perpendicular, according to the stretching of the glacier in its progress. Thus the outcrops of the layers on the surface of the glacier get the appearance of a broken zig-zag line, whose general convexity however is always downwards, showing the quicker progress of the ice in the middle of the glacier.

The origin of the glacier-ice is entirely confined to the firn region. During the cold season the water, filling the hollows, or soaked into the glacier-ice, freezes, it is true, as far as the cold can penetrate, but the belts of ice thus formed are denser, and are distinguished by their transparency and sky-blue colour, from the porous and opaque glacier-ice in whose mass they form riband-like bands.

Since every glacier loses every year a considerable portion of its mass by the thawing which goes on at its surface, its thickness must generally decrease as it progresses downwards. According to the estimations of AGASSIZ the thickness of the ice-mass in the upper parts of the greater Alpine glaciers, amounts to at least 1000 feet, and in some of them is, even at their lower end, nearly 200 feet. Hence arises the enormous thrusting power of the glacier-ice, even when the slope of the valley-bottom is gentle. For instance, in the case of the Mer de Glace, above the vale of Chamouni, CHARPENTIER finds the inclination of the bottom to be from 5° to 6°; the fall would thus amount to about one foot in ten of length. Now, it is known that the pressure is proportional to the steepness of the slope, and it therefore amounts, in the glacier here spoken of, to one-tenth of the weight of the mass of ice. Since the Mer de Glace is about 5400 feet broad, this will give (taking the mean thickness of the ice at only 200 feet), for every 100 feet of the length of the glacier, the immense pressure of 6,500,000 hundred weight, upon all that opposes the onward gliding of the glacier mass.

The notion which has long been rooted among the inhabitants of the Alpine districts, of the descent of the glacier by its own weight, has, since SAUSSURE's careful study of these remarkable phenomena, also obtained the repeated assent of naturalists.

The lower surface of the glacier, that rests on the ground (at least of all great glaciers that descend in valley-channels) is in a state of uninterrupted thaw. This is proved by actual observation in all places where it has been possible to get underneath the glacier. Under many glaciers caverns run up inwards, between the bottom and the ice, to a great length, and branch out into many channels. HUGI, ENNEMOSER, and others* penetrated far up, and crept about under several of these caverns. The ice-vaults, from under which the brooks run at the lower end of many glaciers, are universally known. That these hollows also exist in the upper parts of the glaciers is proved by the little rivulets which even there fall down into the crevices, and whose murmur, as they run on under the ice, may be perceived in many places. When spring sets in, water collects above in many of the holes and crevices, and forms the so-called glacier-pools, which often lie high upon the glacier, until at last they find entrance into the crevices of the interior, and then they generally are drained in a short time, and a sudden swelling of the glacier-stream is the result.

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* The innkeeper, CHRISTIAN BOHREN, fell in the year 1787, on the upper Grindelwald glacier, into a crevice sixty-four feet deep, from which, in spite of his broken arm, he managed to escape, by creeping in the bed of the stream, under the glacier.

Few of these rivulets entirely cease flowing in the winter. Their temperature, whenever it has been examined, has been found above 0° Cent. (32° F.), but seldom higher than 1° C. (33°·8 F.) If we connect with this fact the constant though slow action of the heat of the ground, the springs which probably come up in many places under the glaciers, and the penetration of the external air under the cracked ice-mass, we find causes enough to account for the continual melting of the ice at the bottom of the glacier. Agassiz has shown too, by immediate experiment, that the interior of the glacier-mass has invariably the temperature of melting ice. For this purpose he had a hole bored by degrees down to a depth of two hundred feet. Only at the surface, and at the depth of a few feet, can it be found that there is any fall of the temperature below the freezing point, due to nocturnal radiation. This lowering of the temperature cannot, even in winter, go much farther, because at this season all the glaciers are covered with a thick layer of snow.

The whole mass of the glacier rests on the bottom of the valley, and presses by reason of its weight against the unevennesses on the general slope of the ground. While now the parts of the ice, which rest on the ground, are gradually melting away, the load pressing from above effects an onward movement down the valley.

The progress thus made is not the same in different seasons. Being least, and in many glaciers becoming almost nothing, in winter, it increases towards the spring, and shows itself most strongly when the masses of snow fallen during the winter begin to melt, and the glacier-rivulets are reinforced by the water now coming down from all the mountain-sides, and pouring in at the border of the glacier. In summer they decrease again.

According to the observations of AGASSIZ, the greatest advance takes place in general at the upper parts of the glaciers. The yearly advance at the lower end amounts, in some of the Alpine glaciers, to more than three hundred feet, in others to less. It seems that the most massive glaciers move forward most rapidly. AGASSIZ has reckoned, from the advance of the glacier of the Aar, that its ice must take one hundred and thirty-three years to travel from the limits of the firn down to the source of the Aar.

Very lately some naturalists have tried to attribute the motion of the glacier-ice to other causes than those above treated of. Thus by some, especial stress is laid on the somewhat readier yielding to external pressure, which distinguishes glacier-ice from common ice; by others, on an expansion due to the freezing of the water absorbed by the glacier-ice.

That these theories are untenable, and even opposed to our common physical knowledge, has been shown in very profound and conclusive reasoning by PETER MERIAN. The foregoing statement has been mainly borrowed from his treatise.*

The glaciers from the snowy mountains in high latitudes often come down to the sea-coast. The masses of ice breaking off from these fall into the sea, where they are then driven about by the winds and currents. They form the floating icebergs which sailors so often meet with in the polar seas, and which are sometimes found covered with blocks of stone, with earth and sand. On the coasts of Europe, glaciers reaching down to the sea are only found in Norway, and even there, not below 67° N. L. Along the west coast of South America they occur on the shore of the straits as far as 46°·40 S. L.

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* In POGGENDORFF'S "Annalen," vol. lx.

LETTER XI.

ON THE TEMPERATURE OF THE WATERS, AND ON THEIR INFLUENCE ON CLIMATE.

The temperature of the waters, of the rivers, the lakes, the seas, is, while the heat is increasing, usually somewhat lower than that of the solid ground, if exposed to the same amount of heating influence.

The capacity of water to take heat into its substance, is about four times as great, on the average, as that of the ground; in other words, water requires four times as much heat as does the ground, to raise the temperature of an equal weight of it a given number of degrees. Moreover the rays of the sun penetrate through the water, although with less ease than through the air, to a great depth, before they are wholly absorbed or converted into sensible heat. Their warming power is therefore extended through a greater mass,—a mode of action which is very much favoured by the mobility of water, by the waves and the currents.

Besides, the open surface of the water is subjected, during the day-time, to an almost uninterrupted evaporation ; that is, to say, a part of the heat thrown in from without being employed in making vapour, it passes into the state of combined heat, and ceases therefore to contribute to the raising of the temperature.

When the external temperature is falling, the waters are commonly warmer than the land. It is true that the surface of the water yields up its heat by radiation as readily as does the ground ; but then the water so cooled becomes denser and heavier, and consequently sinks, while some that is warmer rises in its stead, so that nevertheless the cooling can proceed but slowly. Besides, as the temperature falls, the evaporation is diminished, and at last, under certain conditions, of which I shall have to write hereafter, ceases altogether.

The waters, especially where they are in great abundance, tend therefore to draw the limits of highest and lowest temperature close together. They check the direct action of the sun's heat, and contribute in the same manner to moderate the cool of night and the cold of water.

Brooks and rivers, whose depth is but small, soon acquire a pretty uniform temperature through their whole mass. When the external temperature falls below 0° C. (32° F.), that of running water cannot be below 0°, because, at the very first formation of ice, as much of the combined heat of the water is always set free, as is requisite to keep the temperature of the newly-formed ice and of the still liquid water up to 0°. The water running under the ice retains therefore, even in the coldest days of winter, the constant temperature of the freezing point. The surface of ice acquires, as the cold increases, the temperature of the air, and gradually transmits it to the interior of its mass; and for this reason, the formation of ice is always going on, more and more slowly however as the thickness of the layer increases.

Since ice is lighter than water (its specific gravity being 0·916), you would expect that it could only appear at the surface. Nevertheless in rivers we very often find the bottom at the beginning of a frost, coated with ice. The formation of this *ground-ice* is explained by the following circumstances. The growth of ice, like that of any other crystalline substance, is very much promoted by the presence of a solid nucleus, as of a crystal already formed, or of any other solid particle. Thus you will never see the ice first formed in the middle of a bowl of water, but it always starts from the edges, and goes on growing from thence to the middle. However, if a piece of ice is hung in the midst of some freezing water, it will forthwith grow in size by the formation of new ice. If there are no such solid particles present, the temperature of water may be lowered considerably below 0° before it begins to solidify. Thus, then, at the commencement of the frost, the water of a river being cooled down below 0°, is forced in the course of its motion to the bottom, and here first meeting with some solid substance, gives rise to the first formation of the ice on the ground. The ground-ice, by continued additions, increases its growth, and at last, being lighter than the water, mounts to the top; bits of earth, stones, and plants to which it was attached, are carried with it, and thus betray its origin. In stagnant water, ground-ice is never found.

At the bottom of deep lakes the temperature is unchanged from year to year, being in most lakes above 4° C. (39°·2 F.), but never found to be lower. Since water has its greatest density at 4° C., (that is, starting from this temperature, is expanded and made lighter as well by cooling as by heating), it is impossible that stagnant water can be cooled below this degree to any considerable depth. In all deep water-basins, whose surface in the course of the year is cooled to 4°, or below, the bottom must soon be covered with water at 4°, and, as soon as this temperature is there set up, it cannot be changed any more by any influence from without, however great may be the variations at the surface. In the lake of Geneva, the effect of the changes of external temperature, have been traced to a depth of two hundred and forty feet. From this depth downwards to nine hundred and fifty feet an unvarying temperature of 6°·6 C. (43°·9 F.) prevails. In Lake Constance a constant temperature of 4°·5 C. (40°·1 F.) was found at the deepest part; in the Lake of Lucerne 4°·9 C. (40°·82 F.); in that of Neufchatel 5°·C (41° F.), and so on. These slight excesses above 4° have been attributed, and most likely with correctness, to the heat of the bottom. In southern countries, whose temperature, even in the winter months, never falls for any length of time so low as 4° C., the lakes must in general keep up, in their depths, a temperature nearly the same as, but a little higher than, the lowest annual temperature of the locality. The Mediterranean Sea, which by reason of its slight communication with the ocean may almost be considered as a great lake, has, at the depth of from 1000 to 3000 feet, a temperature of 12°·6 C. (54°·7 F.) Its mean temperature at the surface reaches 17° or 20° C. (62°·6 or 68° F.)

In the great oceans the temperature has been examined at many points, at some to depths as great as 6000 feet. It appears that in general it diminishes with the increase of the depth, at first quickly, then more slowly, and at last almost imperceptibly; and it is especially remarkable that even near the equator, where the temperature at the surface of the sea never falls below 25° C. (77° F.) it was found at the depth of 3000 feet and below, to be only 2°·2 C. (35°·96 F.) The water of the ocean does not possess the property, which fresh water has, of attaining its greatest density at a certain temperature; it becomes denser and denser the more it is cooled, till at last at a temperature of −3° or −4° (26°·6 or 24°·8 F.) it solidifies. At the moment of freezing the greatest portion of its dissolved salt separates, so that the ice formed from sea-water possesses almost perfectly the properties of, and is quite as light as, ice obtained from pure water. Thus sea-water, so long as it remains liquid, while cooling goes on, increases in weight, and sinks, leaving its place to the warmer liquid that flows in to supply it; and so the cooling of its surface must reach gradually to very great depths, and therefore can go on but very slowly at the surface itself. This then explains how it is that we find open water, at some distance from the coast, even within the Arctic Circle in the middle of winter. In the Polar Sea, too, at several points, the temperature has been examined even to the depth of 6000 feet. It seems that it cannot anywhere sink much below −2° C. (28°·4 F.) The bottom of the sea has nowhere been found frozen.

The following table shows the most probable mean temperatures at the surface of the Atlantic Ocean in different latitudes:—

Degrees of Latitude.	Mean Temperature in Degrees.			
	Northern Hemisphere.		Southern Hemisphere.	
	Cent.	Fahr.	Cent.	Fahr.
0	26	78·8	26	78·8
10	27·5	81·5	27	80·6
20	24·1	75·4	24·1	75·4
30	21·5	70 7	22·2	71.96
40	15	59	15·5	59·9
50	8·3	46·94	9·2	48·56
60	6·9	44·4		
70	4·25	39·65		
80	—1·3	34·34		

The temperature of the Pacific Ocean, is as yet but little known. However, it has been shown that it probably remains everywhere in the temperate and polar zones, under the same latitudes, about two or three degrees below that of the Atlantic Ocean.

The oscillations about the mean temperature of the year, that is to say the risings and fallings above and below that point, are very small in the open sea, and in temperate latitudes, where they seem to be greatest scarcely amount to two or three degrees (3°·6 C. or 5°·4 F.)

The scope of the daily variations is naturally still narrower at a distance from the coasts. The air which plays over the sea cannot have a temperature differing very much from that of the surface of the water; and it is clear that this air, driven by the wind to the coasts, must exert a powerful influence in equalizing the differences of the temperature on the land. In fact the farther we go towards the interior of the country, the greater do we find the fluctuations of the temperature of the air and of the ground.

The temperature of bays and of inland lakes, is, on account of the neighbouring masses of surrounding land, subject to considerably greater oscillations than is that of the ocean. Thus the mean summer temperature of the Baltic is about 15° or 17°·5 C. (59° or 63°·5 F.), and on some summer days it is found to amount to 20° or 23° C. (68° or 73° F.), while large tracts of this sea are frozen in the winter.

In the following table are collected some instances of the extreme temperatures which have been observed in the air at the places whose names are given :—

Place.	Latitude.	Temperatures observed, in Degrees.			
		Lowest.		Highest.	
		Cent.	Fahr.	Cent.	Fahr.
	° ′				
Quito*	0·14 S	6	42·8	22	71·6
Singapore	1·17N	21·7	71·06	31·7	89·06
Madras	13·5	17·8	64·04	40·3	104·54
Martinique	14·36	17·1	62·78	35	95
Otaheite	17·29	18·3	64·94	32·2	89·94
Honoruru (Sandwich Islands).	21·19	8·9	47·5	31·1	87·98
Calcutta	22·35	11·1	51·98	37·2	98·94
Canton	23·8	2·2	35·96	35·6	96·08
Funchal	32·8	10·6	51·08	29·4	84·92
Bagdad	33·21	5	41	48·9	120
Algiers	36·47	2·5	36·5	38	100·4
Lisbon	38·42	2·7	36·86	38·8	101·84
Pekin	39·54	15·6	60·28	43·1	109·58
Cincinnati	39·6	27	80·6	42	107·6
Rome	43·57	5·9	42·6	31·3	88·34
Prague	50·5	27·5	81·5	35·4	95·72
Penzance	50·7	4·4	39·92	28·9	84
Brussels	50·51	22·5	72·5	35	95
London	51·31	20·6	69·08	35.6	96·08
Berlin	52·31	30	86	39·3	102·74
Copenhagen	55·41	32·7	72·86	32·9	91·2
Moscow	55·45	42·2	107·94	36·2	97·14
Yakutsk	62·1	58	136·4	30	86
Drontheim	63·25	23·7	74·66	28·7	83·66
Reikiavig	64·8	20	68	20·5	68·9
Enontekis	68·40	50	144·5	26	78·8
Felix Harbour (Boothia).	70	50·8	145·94	21·1	69·90
Coast of Nova Zembla East	70·37	40	104	10	50
Coast of Nova Zembla West	73	46·9	116·4	13·7	55·66

* The extreme limits of temperature at Quito, at a height of eight thousand nine hundred feet, show in a striking manner the decrease of the fluctuations of temperature due to the increase of height.

A glance at this table will show you at once that the extreme limits of temperature approach each other most closely near the coasts and on islands; that, on the other hand, in the interior of the continents, they diverge; and that severe cold in winter, and in a still greater degree, the heat of the summer, depends more upon the position of a place in the interior of the mainland, than upon the latitude. Warm summer days are met with everywhere except in the extreme north, where the sun has no longer the power to melt the ice and snow that has been stored up during the long winter.

Over the open sea, even in the hottest parts of the world, the temperature is seldom found as high as 30° C. (86° F.), and never above 31° C. (87°·8 F.) It is as warm as this in some days of summer at Yakutsk, although in winter at that place mercury is often solid under the hammer for months together. While the changes of temperature on the ocean are confined within bounds of 3 or, at most, 4 deg. C. (5·4 or 7·2 deg. F.), yet fluctuations of 40 or 50 deg. C. (72 or 90 F.) are quite common in inland countries, especially in high latitudes. At Moscow a difference of 78·4 deg. C. (141·1 F.), and at Yakutsk even of 88 deg. C. (158·4 F.) have been observed. Degrees of cold above − 50° C. (−58° F.) are by no means uncommon in the most northern countries; but it does not appear that −60° C. (−76° F.) has yet been observed anywhere in the open air. The temperature seems to rise sometimes at many places to the same distance above 0° C. (32° F.), as at other places it falls below that point. At Suez, at the time of the

French expedition, we are told that the thermometer rose once to 52°·5 C. (126°·5 F.); and at Murzouk (in Fezzan) LYON says that he saw it at 56°·2 C. (133°·16 F.) Certain it is that the variations of temperature occurring on the earth extend over 100° C. (180° F.)

It is indeed remarkable, that the human body is not only able to bear exposure to these changes, but can even become accustomed to them. Moreover, the experience of many travellers agrees in this, that an unusually severe cold in still air is more easily endured than an unusually high heat. It is clear that man has readier means of sheltering himself from the former than from the latter; besides this, extreme degrees of cold are very seldom attended with much motion in the air. Cold winds, however, as you probably know from experience, are more distressing, than mere exposure to very far lower temperature. Sir JOHN ROSS and his sailors moved about, and worked, without much inconvenience in the open air, under cold which froze mercury, although they found the effect of a strong wind, only a few degrees below the freezing point of water, quite insupportable.

DARWIN mentions several instances of travellers having been frozen by violent storms in the mountain passes of Northern Chili, when the thermometer stood but little below the freezing point, and snow was not falling.

It is not so much the lowering of the temperature without, as the amount of heat carried off from the body, that affects the feelings. This loss of heat increases so much the more, the oftener the small quantity of air is changed, which at every instant is touching the body. Hence it is that the wind robs the human body of more heat, although the mercury of the thermometer may not fall very much, than a far greater degree of cold in still air does. Our clothes, which in themselves are quite devoid of warming power, can give us but little protection against the cold, except by retarding the change of the air, which is the only way by which the cold makes itself felt. Thus, as you well know, garments that are pretty loose and full are warmer than such as are light and close-fitting, because the former shut in a layer of air between the body and the outer covering.

You will get a clear notion of the great influence of the large oceans upon the climate of the neighbouring lands from the following table.

TABLE

OF THE MEAN WINTER AND SUMMER TEMPERATURES AT VARIOUS PLACES, WHICH ARE ARRANGED, AS FAR AS POSSIBLE, IN THE ORDER OF THEIR MEAN YEARLY TEMPERATURES.

Places.	Latitudes.		Degrees of Temperature.							
			Means of the						Differences of Winter and Summer.	
			Year.		Winter.		Summer.			
	Deg.	Min.	Cent.	Fahr.	Cent.	Fahr.	Cent.	Fahr.	Cent.	Fahr.
Melville Island	74 ,,	45	—18·5	— 1·3	—33·5	—28·3	2·8	37·04	36·3	65·34
Boothia	70 ,,		—16·88	1·62	—33·26	—27·87	3·09	37·56	36·35	65·43
Ustyansk	70 ,,	35	—16·4	2·5	—37·9	—36·2	9·2	48·56	47·1	84·78
Coasts of Nova-Zembla, East	70 ,, to		— 9·45	14·99	—20·27	— 4·48	2	35·6	22·27	40·08
Coasts of Nova-Zembla, West	73 ,,		— 8·37	16·93	—19·05	— 2·29	3·6	38·48	22·65	40·77
Yakutsk	62 ,,	1	— 9·7	14·54	—42·5	—44·5	16	60·8	58·5	105·3
Fort Enterprise (North America)	64 ,,	28	— 9·2	15·44	—31·27	—24·28	15	59·0	46·27	83·28
Nain (Labrador)	57 ,,	10	— 3·6	25·32	—18·5	— 1·3	7·8	46·04	26·3	47·3
Enontekis (Lapland)	68 ,,	30	— 2·7	27·14	—17·6	+ 0·32	12·8	53·04	30·4	54·72
Beresow (Obi)	63 ,,	54	— 3·0	26·6			18	64·4		
Tobolsk	58 ,,	13	— 2·4	27·48						
North Cape (Norway)	71 ,,	10	+ 0·1	32·02	— 4·6	+ 23·72	6·4	43·32	11	19·9
Uleaborg (Finland)	65 ,,	3	+ 0·7	33·26	—11·1	+ 12·01	14·3	57·74	25·4	45·74
Slatoust (Siberia)	55 ,,	8	+ 0·3	32·54	—16·5	+ 2·1	16·1	60·99	32·6	60·48
Irkutsk	52 ,,	16	— 0·2	31·64	—17·9	— 0·22	16	60·8	33·9	61·02
Cumberland House (Saskatchewan)	53 ,,	57	0	32	—19·8	— 3·64	19·68	67·42	39·48	71·06

Places.	Latitudes.		Degrees of Temperature.							
			Means of the						Differences of Winter and Summer.	
			Year.		Winter.		Summer.			
	Deg.	Min.	Cent.	Fahr.	Cent.	Fahr.	Cent.	Fahr.	Cent.	Fahr.
Eyafiord (Iceland)	66 „	30	+ 0·2	32·36	— 6·2	20·84	7·7	43·86	13·9	25·02
Reikiavig	64 „	8	3	37·4	— 3	26·6	9·7	49·46	12·7	22·86
Moscow	55 „	45	3·8	38·84	—11·4	11·48	18·5	65·30	29·9	53·82
Faroe Islands	62 „	2	7·1	44·78	+ 3·9	39·02	11·6	52·88	7·7	13·86
Unst (Shetland)	60 „	45	7·5	45·5	4·07	39·33	11·92	53·45	7·85	14·13
Bergen	60 „	24	6·7	44·06	2·2	35·96	14·8	58·64	12·6	22·68
Königsberg	54 „	43	6·5	43·7	— 3·3	26·06	15·9	60·62	18·2	32·76
New Archangel (Sitkha Isle)	57 „	3	7·4	45·33	+ 0·7	33·26	12·7	54·86	12	21·60
Fort Howard (Lake Michigan)	44 „	4	6·9	44·42	— 7·2	19·04	20·6	69·08	27·8	50·06
Montreal	45 „	31	6·4	43·52	— 8·1	17·42	20·6	69·08	28·7	51·66
Halifax	44 „	39	6·2	43·16	— 4·4	24·08	17·2	62·96	21·6	38·88
Dublin	53 „	21	9·6	49·28	+ 4	39·50	15·3	59·55	11·3	20·34
London	51 „	31	9·8	49·64	3·2	37·76	16·7	62·06	13·5	24·30
Haarlem	52 „	23	10	50	2·9	37·22	17	62·60	14·1	25·38
Treves	49 „	46	9·8	49·64	1·8	35·24	17·8	64·04	16	28·80
Frankfort	50 „	7	9·8	49·64	1·4	34·52	18·3	64·94	16·9	30·42
Würzburg	49 „	48	10	50	0·7	33·26	19·1	66·38	18·4	33·12
Prague	50 „	5	9·8	49·64	— 0·2	31·64	19·9	67·82	20·1	36·18
Ofen	47 „	30	10·4	50·72	— 0·4	31·28	21·2	70·16	21·6	38·88
Odessa	46 „	29	9·1	48·38	— 2·3	27·86	20·1	68·18	22·4	40·32
Fort George (Columbia)	46 „	1	9·3	48·74	+ 3·7	38·66	15·5	59·90	11·8	21·24
Council Bluffs	41 „	25	10	50	— 4·6	23·73	23·6	74·48	28·2	51·76

Places.	Latitudes.		Degrees of Temperature.							
			Means of the						Differences of Winter and Summer.	
			Year.		Winter.		Summer.			
	Deg.	Min.	Cent.	Fahr.	Cent.	Fahr.	Cent.	Fahr.	Cent.	Fahr.
Boston (Massachusets) .	42 „	21	9·6	49·28	—1·4	29·48	21	69·8	22·4	40·32
St. Louis (Missouri) . .	38 „	36	12·9	55·22	+0·3	32·54	24	73·2	23·7	42·66
Cincinnati (Ohio) . .	39 „	6	12·4	54·32	+0·5	32·90	22·8	73·04	22·3	40·14
New York	40 „	43	12·1	53·78	—1·2	29·82	26·2	79·16	27·4	49·32
Nantes.	47 „	13	12·6	54·68	+4·4	39·92	20	68.00	24·4	43·92
Milan	45 „	28	12·9	55·22	2·4	34·20	22·8	73·04	20·4	36·72
Padua	45 „	24	12·5	54·5	1·7	35·97	23·1	73·58	21·4	38·52
Naples.	40 „	51	15·3	59·54	8·7	47·66	22·8	73·04	14·1	25·38
Palermo	38 „	7	17·2	62·96	11·1	51·98	22·6	72·68	11·5	20·70
Lisbon.	38 „	42	16·6	61·88	11·4	52·52	21·6	70·88	10·2	18·36
Natchitoches (Louisiana)	31 „	30	20·2	68·36	11·9	53·42	28·4	83·12	16·5	29·70
Santa Cruz (Teneriffe) .	28 „	28	21·6	70·88	18·1	64·58	24·8	76·64	6·7	12·06
Cairo	30 „	2	22·2	71·96	14·7	58·46	29·3	84·74	14·6	26·28
Macao	22 „	11	22·5	72·5	15·2	59·36	28·2	82·76	13	23·40
St. Augustine (Florida) .	29 „	50	22·3	72·14	15·3	59·54	28·2	82·76	12·9	23·22
Havanna	23 „	9	25·2	77·36	22	71·60	28·5	83·3	6·5	11·70
Vera Cruz	19 „	12	25·4	77·72	21·6	70·88	27·7	81·86	6·1	10·98
Benares	25 „	19	25·4	77·72	17	62·6	30·4	86·72	13·4	24·12
Calcutta	23 „	35	25·8	78·44	19·5	67·1	28·5	83·3	9	16·20
Madras.	13 „	5	27·8	82·04	25	77·0	30·1	86·18	5·1	9·18
Trincomalee (Ceylon) .	8 „	34	27·1	80·78	25·7	78·26	28·4	83·12	2·7	4·86
Cumana.	10 „	28	27·4	81·32	26·2	79·16	29·1	84·38	2·9	5·22
Maracaybo.	10 „	34	29·3	84·74	27·8	82·04	30·4	86·72	2·6	4·68

The great difference of the extreme limits of temperature, as well as that of the temperatures of winter and summer at different places, according as they are more or less distant from the ocean, has led to a distinction being drawn between the *Continental* or *Inland Climate,* and the *Island* and *Coast Climate.* The temperature of an island must, by means of the air, be brought to agree the more nearly with that of the surrounding sea, the less its circumference is, and the farther it lies from the mainland. If, for instance, you compare the difference of the mean winter and summer temperatures at Teneriffe with that of Cairo; that of the Faroe Isles with that of Königsberg or of Moscow; that of Iceland or of the North Cape with that of Irkutsk; that of Dublin with that of Prague, and so on; you will readily perceive that the inland-climate becomes the more marked the farther the places lie towards the interior of the continent. You will observe, however, that the western coasts of the continents partake of the island climate more than do the eastern. These characters at least are distinct in the northern parts as well of the old continent as of the new.

It is only by the knowledge of the mean summer and winter temperature of a country that you will be enabled to form a correct judgment of its fitness for being inhabited or cultivated, as well as of its entire character. At Bombay, Pondicherry, and on the whole Coromandel Coast, and on the Island of Ceylon, districts of such uncommon fertility, and so well known for the luxuriance of their vegetation, and shown by their mean annual temperature of 27° C. (80°·6 F.), to be among the warmest on the globe, are, nevertheless, no hotter, but even generally more temperate, than the North of India, than Central Egypt, or than Louisiana, where, however, the mean temperature is lower. It is these high summer temperatures that enable us to grow cotton—a plant which is a native of the torrid zone—with advantage, at many places far beyond the tropics; as, for instance, in the Southern States of North America, in Egypt, in Asia Minor, and even on the southern coasts of Europe. On the southern coast of Iceland, the yearly mean of temperature is not lower than at Petersburg, and the winter but little colder than at Odessa. However the peasants of this island, on account of the coolness of the summer months, can do little farming beyond the breeding of cattle, and the so-called forests there consist of nothing but stunted birch. In the Faroe Islands, where in winter it is warmer than at Milan, on the Island of Sitkha on the coast of Russian America, and on the Falkland Isles, the same mean temperature is found as at Dantzig, and a higher than at Königsberg. But while the eastern provinces of Prussia are pretty thickly occupied by an active agricultural population, on these islands the only corn produced is a poor barley, which however can ripen with a mean summer temperature no higher than 8° C. (46°·4 F.) It is true that their winters are not very severe, but the summer fails to supply the warmth requisite for the usual cultivated crops. At the North Cape even barley can no longer be cultivated, and the birch, which a little farther south, under 76° north latitude, is still met with, here disappears. On the same isotherm in the country about the Cumberland-house Factory, and in the neighbourhood of Lake Winnipeg, in the interior of North America, the ground is, as we are assured by travellers, covered with forests, and is fruitful, and well fitted for the growth of corn. Even at Yakutsk, with a mean temperature for the year of −9°·7 C. (14°·54 F.), and for the winter months −42°·5 C. (−44°·5 F.), forest trees, and all plants which, like wheat and rye, only need a short but hot summer, grow well, because the mean summer temperature, notwithstanding the ever-frozen sub-soil at three feet depth, is as high as 16° C. (60°·8 F.), and is thus equal to that of Stockholm and of Königsberg. In Nova Zembla the year gives the mean temperature as at Yakutsk. Nevertheless this island is quite uninhabitable, and devoid of vegetation, because the mean summer temperature does not rise above 2°·5 C. (36°·5 F.) The warmest day in the year gets but 11°·9 C. (53°·42 F.) On the west coast, and on the still colder east coast only 7°·6 C. (45°·68 F.) There are small towns in the parts of Siberia much farther north, and having a still lower mean annual temperature than Yakutsk. Thus Ustyansk, a little town at the mouth of the Yana, has, with a mean temperature for the year of −16°·4 C. (2°·48 F.) a mean for the summer of 9°·2 C. (48°·56 F.) and, therefore, a considerably warmer summer than the North Cape of Europe, which lies under the same latitude, and whose mean yearly temperature reaches 0°·1 C. (32°·18 F.)

Thus you see that the most inhospitable places on our earth are not those in which the mean temperature is the lowest, but those in which the summer does not supply warmth sufficient for the growth of plants.

The most northern spots permanently inhabited by man, and the last traces of cultivation of the soil, are in Siberia beyond 70° N.L., while in America they do not extend even to the Arctic circle. The various bays and straits which branch through the high north of America, and which are all frozen in winter, can contribute as little as the numerous lakes of the interior, to any actual mitigation of the winter-cold, while, however, they prevent the temperature of summer from reaching any great height. For there the whole summer season sometimes passes without having sufficed to thaw the covering of ice, nine or ten feet thick, with which in winter all the water basins are covered. The temperature of the air cannot rise here very far above the freezing point, and the warmer air, which the south wind may bring, is soon cooled down to the temperature of the sea. According to SCORESBY, the sea freezes in clear, still nights, even when the temperature falls only to a very little below 0° C. (32° F.) ROSS found the temperature of the sea water under the ice, even in the middle of winter, no lower than 2°·8 C. (36°·96 F.) At the beginning of winter the neighbourhood of the sea, as well as the heat set free by the formation of ice, must certainly somewhat retard the progress of the cold; but this influence ceases as soon as a solid crust of ice is formed, which is the case on the seas bounding the extreme north of America, at the end of September, or at the beginning of October. All the conditions of a continental winter now come into play, and must necessarily bring about the results, which always follow them. This explains why the islands and peninsulas on the north-east of America, which are, next to Nova Zembla and Spitzbergen, the most inhospitable in the northern hemisphere, can produce nothing but some scanty grass and a few lichens. PARRY found the mean summer temperature on Winter

Island (N. L. 66°) to be 2° C. (35°·6 F); and on the island of Igloolik, even so low as 1°·8 C. (35°·24 F.) In Boothia, Ross found it 3°·1 C. (37°·58 F.); the thermometer rising only once as high as 16°·7 C (62°·06 F.)

It has been proposed to connect places of equal winter cold, and those of equal summer heat by lines, the first sort of lines being called *Isocheimenes*, and the second *Isotheres*. The isocheimenes pass southwardly from the west coast of Europe towards the interior of the continent. For instance, the Faroe Islands, Aberdeen, Edinburgh, London, Paris, have the same mean winter temperature. The isotheres, in their eastward course, tend somewhat to the north. Thus the towns Nantes, Paris, Frankfort, Dresden, Berlin, Moscow, Casan, and Beresow, have nearly the same summer temperature.

The dissimilarity, however, of the inland and island climate is shown not only in the difference between the winter and summer temperature, but also in the contrast between the day and night. So long as we are ignorant of the extent of this latter difference in any country, our notion of its climate will be but imperfect, and all our conclusions as to the limits of distribution of its animals and plants liable to error. For instance, in the south of England, in Belgium, and in the Netherlands, where the mean summer temperature is the same or nearly the same as that of the Rheingau and the Palatinate, it is not nearly so hot as in these latter districts, because here the hotter days alternate with colder nights. In Bretagne and Normandy the nights are less cold, and the days, on the other hand, are less warm than in the regions to the south of Nantes, Paris, Rheims, Luxemburg, and Treves.

This circumstance explains why the cultivation of the vine, which, though it requires a mean temperature no higher than 9° C. (48°·2 F.), must have a warm and long summer, cannot be carried on in France beyond a little to the north of a line drawn through the cities which I have just mentioned. It explains, too, why the fig, which will not grow under a mean temperature of 9° C., but does not require so great a heat as the vine does to ripen its fruit, yet grows extensively and thrivingly in Normandy. In Germany the growth of the vine extends considerably farther to the north than in France, generally beyond 50° N. L., and, in certain parts of Eastern Germany, even so far as to nearly 52½° N. L. But, in fact, the grapes ripen only in favourable years; that is, in such as afford many warm days, and especially hot days in September, even at the cost of coldish nights; for in general, the mean summer temperature of one year differs but little from that of another. Farther in the interior of the old continent, in Russia and in Asia, the vine is not again found in cultivation so far north as 50° N. L., and in Asia it seems to be confined within a more southern limit. It is true that, in the regions north of 50° N. L., there are plenty of hot days in their summer, but that summer is too short, and in September, just at the time when the grape begins to ripen, there is no longer sufficient heat in the day. And the vine-plant cannot bear the cold of the continental winter. The heat of the torrid zone is equally little suited to the growth of the vine. Generally therefore it does not grow within the tropics.

Any great abundance of water in a country, numerous lakes, swamps, marsh-lands, and extensive forests, in which the moisture of the air is retained, and gradually dissipated into the atmosphere by evaporation, exert, to some extent, the same influence as the sea, in mitigating the cold of winter, and in lowering in turn the heat of summer. By the draining of swamps, and the cutting down of forests, the escape of the water is hastened, and at the same time a greater extent of the ground is exposed to the immediate influence of the sun; the limits of temperature of the day, as well as of the year, are removed farther and farther apart; the summers become warmer, the winters colder, without any accompanying alteration in the whole effect of the sun. This explains the gradual change in the climate of countries, which have been inhabited for thousands of years. Thus there can be no doubt that Egypt, if it were covered with forests, would have much more rain than it has at present, and a much milder climate.* The range of temperature, which varies between about 9° C. (48°·2 F.) and 47° C. (116°·6 F.), would certainly be contracted within closer limits, and the cultivation of the vine might again come to be of as much importance there, as it seems to have been three thousand years ago.

Similar causes may have wrought in Cyprus and in Greece, in Syria and in the now dry tablelands of Asia Minor and of Persia, and may have spoiled the mildness and fertility which once characterised their climate and their soil. These injurious results have without doubt arisen from thoughtless management, and from the gradual and almost total extirpation of the forests, by which means one of the chief conditions was removed, on which depended the moisture of the soil and air,—next to the sun, the most effectual promoter of fertility.

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* Marshal MARMONT states that in Upper Egypt, eighty years ago, a considerable amount of rain used to fall. However, since the Arabs have cut down the trees on the mountains on the border of the Nile valley, towards Lybia and Arabia, the rains have ceased, and the meadows have dried up. In Lower Egypt the contrary effect has been observed. It rained very seldom at Cairo, at the beginning of this century; according to the testimony of MARMONT, it rained at Alexandria from November, 1798, to the end of August, 1799, only once, and that for only half an hour. Since that time the Pasha has had many millions of trees planted there; and now, it is stated that, in consequence of this, they have there from thirty to forty rainy days in the year, and that in winter it often rains for five or six days together.

It seems, too, that the climate of Germany was formerly different, and more severe than at present. There are strong reasons for this belief. In the time of the Romans, Germany was covered with an almost unbroken forest.

It abounded in swamps; its atmosphere was moist. Many plants, as the chesnut, the vine, the finer sorts of fruit, and probably many of the cereal grains, which require a high summer temperature, could not grow two thousand years ago, in places where they are now thriving, since the clearing of the forests has favoured the draining off of the water, and by the removal of the excess of moisture has improved the climate, and enhanced the fertility of the soil. If however the destruction of the still numerous forests, with which the mountains and many of the plains of Germany are clothed, continues, the brooks and rivers must dry up more and more during summer, because the wet that falls in winter and spring will find a freer outlet. The summer showers will probably diminish as the heat of the summer increases, and the fruitfulness of the soil must diminish with the moisture of the ground and air. From this you will conclude, that the statement is as unrighteous and false as its truth would be disheartening,—that the long occupation of a country and the continued use of its soil must end in the gradual deterioration of its climate, and in the decay of its fertility;—and you will see that wherever these results have followed, they have come from man's ignorance of the laws of God's earth, and that they may be avoided by a wise economy, and especially by careful provisions against the destruction of the forests.

LETTER XII.

THE CURRENTS OF THE SEA.

I HAVE already mentioned to you that the water of the ocean, at great depths, has a temperature, even under the equator, nearly approaching to the freezing-point. This low temperature cannot depend on any influence of the sea-bottom, since, from all we know of the condition of the mass of the earth, as regards heat, we may be sure that the ground cannot tend to cool the water, though it may have some effect in warming it. Again, we know that the water at the bottom of lakes, and of the southern inland seas, has by no means so low a temperature. The fact however is explained by a continual current of cold water flowing from the polar regions towards the equator.

The following well-known experiment clearly illustrates the manner of this movement. A glass vessel is to be filled with water with which some powder has been mixed, and is then to be heated at bottom. You will soon see, from the motion of the particles of powder, that currents are set up in opposite directions through the water. Warm water rises from the bottom, up through the middle of the vessel, and spreads over the surface, while the colder and therefore heavier liquid falls down at the sides of the glass. Currents like these must arise in all water-basins, and even in the oceans, if different parts of their surface are unequally heated.

The water that is cooled in the polar regions sinks and travels from the poles towards the equator, pushing away the warmer and lighter liquid from the bottom of the sea, itself to give way in turn, as it gets warm, to the colder water that follows after it. This continual flow of the water from the cold zones is replaced in a twofold manner. The warm water of the tropical seas, since it is the lightest, must spread itself north and south over the surface of the ocean, and thus, gradually losing its heat, be carried to the polar regions. Between the tropics, too, evaporation goes on most vigorously, and a great part of the vapours formed fall again in rain and snow only in higher latitudes.

The direction of the surface-current of water setting from the equator to the pole, and that of the opposite movement in the depths of the ocean, are somewhat altered by the turning of the world round its axis. It is clear, that the only reason that we do not perceive the ceaseless turning of the earth from west to east, is because all the bodies near each other, at any given spot, share equally in the motion. However, the speed of the movement is not the same under different parallels of latitude, but is less and less from the equator to the poles. Under the latitude of 60°, it amounts to about seven hundred feet in a second, while at the equator it is as much as fourteen hundred. If therefore a body were to be suddenly transported to the equator from the former latitude, retaining the speed with which it had there been moving round, it must lag behind the bodies, which it found at the equator, and which have a rate of fourteen hundred feet in a second; and the same effect would result to the observer as if this body were travelling from *east to west* with a speed of seven hundred feet in a second. If, on the contrary, any body moving with the speed due to the equator were to be brought to any higher latitude, it must outrun all other bodies there, in the direction from *west to east.*

From this you will see that all the ocean-water which flows from the poles to the equator must gradually take up a direction of motion from east to west, and that all water flowing from the equator to the poles must take one from west to east.

But differences of temperature are not the only cause which give rise to currents in the sea. We everywhere see how the wind rouses the water and increases the force of the waves, and we know that by mighty storms the flow of rivers may be stopped, and the sea stirred up to great depths; must we not then expect that long-lasting winds, even of moderate strength, must tend powerfully to impress upon the sea a movement in their own direction?

Such indeed is the case, and especially with the constant easterly winds of the tropics, and with the west winds which are so prevalent in higher latitudes. The influence of these winds joins with that of the differences of temperature in urging the waters of the tropical seas to the west, and those of the temperate zones to the east. Lastly, the tides whose course is from east to west tend to establish currents in the same direction, and these may enhance the general westward flow of the tropical seas.

The sea-currents have been most carefully studied in the Atlantic Ocean. In this ocean too the conditions of their origin and direction are very obvious, although the latter suffers considerable modifications from the form of the coast, and most likely of the sea-bottom. Near the equator, and close to the African coasts, the mighty *Equatorial Stream* sets out. Here, to the south of the islands of St. Thomas and Anna Bon, it has a speed of forty miles in twenty-four hours, and a temperature of 23° C. (73°·4 F.) Increasing quickly in bulk, and spreading out more and more on both sides of the equator, it flows rapidly due west towards the coast of South America. In the mid-sea, between the two continents, a branch strikes off from it to the north-west, and loses itself at last by its continual widening out, about the twentieth degree of latitude.

The main stream runs farther west. At the eastern point of South America, Cape Roque, it splits into two arms. One of these, the southern, washes the coast of South America, and, between the tropic of Capricorn and the mouth of the La Plata, beyond the limit of the constant east-wind, turns gradually to the south-east. It may be traced, in a direction south-east from the Cape of Good Hope, far into the Indian Ocean. The northern arm of the equatorial current follows the north-east coast of South America, gaining continually in temperature under the influence of the tropical sun. Its speed has now increased to sixty-eight miles in twenty-four hours, and by the union with it of the waters of the river Amazon, rises to one hundred miles (6·5 feet in a second), but it soon falls off again when it gets into the Caribbean Sea. Flowing slowly through the whole length of this sea, it reaches the Gulf of Mexico, through the Straits of Yucatan, where a part of it immediately sweeps round Cuba; but the main stream nearly follows the coast-curve of the Gulf, and at last, pouring out between Florida and Cuba, takes the name of the *Gulf Stream.* Narrow at first, it flows round the peninsula of Florida, and, with a speed of about seventy or eighty miles, follows the coast at first in a due north, afterwards in a north-east direction. At the latitude of Washington, it leaves the North American coast altogether, keeping its north-eastward course; and, to the south of the St. George's and Newfoundland Banks, it spreads its waters more and more over the Atlantic Ocean, as far as the Azores.* At these islands a part of it turns southwards again towards the African coast.

The gulf-stream has, so long as its waters are kept together along the American coast, a temperature of 80° C. (176° F.) But even under north latitude 36°, SABINE found it at 23°·3 C. (74° F.) at the beginning of December, while the sea-water beyond the stream showed only 16°·9 C. (62°·5 F.) Under north latitude 40°—41°, the water is, according to HUMBOLDT, at 22°·5 C. (72°·5 F.) within, and 17°·5 C. (63°·5 F.) without the stream.

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* It is well known that the fact of many remains of tropical plants, as well as the corpses of two Indians, having floated to the Azores about the end of the fifteenth century, helped to strengthen COLUMBUS in his belief of the existence of a land in the West.

A great part of this warm water is carried, partly by its own motion, but chiefly by the prevailing west and north-west winds, towards the coasts of Europe,* and even beyond Spitzbergen and Nova-Zembla; and thus a part of the heat of the south reaches far into the Arctic Ocean. Hence, on the north coast of the old continent, we always find drift-wood from the southern regions, and on this side, the Arctic Ocean remains free from ice during a great part of the year, even as far up as 80° north latitude; while on the opposite coast (of Greenland) the ice is not quite thawed even in summer. In the two seas that bound this latter peninsula, a current of cold water is found running from north to south; it has been traced as far as Spitzbergen on the eastern side of Greenland, and up to Barrow's Straits in Baffin's Bay. These two currents form the only outflow of water from the Arctic Ocean that can be perceived at the surface. The temperature of this stream at Newfoundland has been found to be 7° C. (12°·6 F.) below that of the air in May. It brings down in the spring great masses of drift-ice, which are carried from the Polar Sea between Greenland and Spitzbergen, as well as from Baffin's Bay and the coasts of Labrador, often nearly as far south as north latitude 40°, and which are not melted away till they get into the gulf-stream. Vast masses of ice attach themselves in winter to all the coasts of North America as far south as 50° north latitude, fill the great lakes, and hang about the coasts a great part of the early summer; while the opposite coasts of Europe, washed as they are by comparatively warm sea-currents, remain in great part free from ice, even during the winter. These conditions are one chief cause of the great difference between the climates of the coasts of Europe, and of the east of North America, under the same latitudes.

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* It has twice happened, in the years 1682 and 1684, that Esquimaux, driven by storms from their own coasts, have been carried by these easterly currents, in their wretched seal-skin boats, to the Orkney Islands.

The equatorial stream is not supplied only by under-currents; that is, its waters are not drawn from the depths of the sea alone. I have already mentioned that a part of the gulf-stream, on reaching the Azores takes a southern direction, and turns down towards the African coast. A similar southward movement of the ocean-water is remarked between the coast of Portugal and the Azores. It keeps close to the coast of Africa, and about the Cape Verde Islands increases more and more in strength. Farther south this current bends with the coast, and flows along that of Guinea with considerable swiftness exactly from west to east, so that here there are two strong currents running near each other in opposite directions. The temperature of the Guinea current is, by reason of the hot north-east wind that blows from the continent, some degrees higher than that of the equatorial stream, into which the former does not pass till it is turned again by the African coast about the equator.

A second current comes from the south, bringing cold water to supply the equatorial stream. This comes from the Indian Ocean, from which it flows in a west and south-westward direction on both sides of the island of Madagascar, towards the southern end of Africa; it sweeps round the Cape of Good Hope, bends to the north, and, gradually taking a more westward course, loses itself at length in the equatorial stream.

The South Atlantic Ocean, beyond 40° south latitude, is not heated, like the seas that wash the coasts of Europe, by warm currents; but, on the contrary, it is everywhere open to the free entrance of the cold waters of the Antarctic Ocean, and of the drift-ice, during the summer months. The most southern parts of America, Terra del Fuego, the Falkland Isles, South Georgia, Sandwich-land, and other islands of the southern ocean, have therefore a very considerably lower temperature than have the coasts and islands of Europe under similar latitudes. Compare for instance the temperature of the Falkland Isles and of Port Famine, in the Straits of Magellan, with that of Dublin, whose latitude is nearly the same.

	Latitude.	Degrees of Mean Temperature.					
		Of Winter.		Of Summer.		Of the Year.	
	Deg. | Min.	Cent.	Fahr.	Cent.	Fahr.	Cent.	Fahr.
Dublin . . .	53 „ 21 N.	4·0	39·2	15·3	66·29	9·6	49·28
Port Famine .	53 „ 38 S.	0·6	33·08	10·0	50	5·3	43·79
Falkland Isles	52 „ S.	4·36	39·83	11·8	53·24	8·24	46·83
Faroe Isles .	62 „ 2 N.	3·9	39·02	11·6	52·88	7·1	44·78

The climate of the Falkland Isles differs, as you will see, but little from that of the Faroe Isles, although the latter lie about ten degrees of latitude farther from the equator. We may assume, with the greatest likelihood, that the coasts of northern Europe owe these favourable conditions of their climate only to the warm water, which is spread over the Atlantic Ocean by the currents, especially by the gulf-stream, and which is forced by the form of the continents to find its way into the Arctic Ocean. If the equatorial current found a passage, between North and South America, into the Pacific Ocean, instead of being obliged, as it now is, to pour the whole of its water, heated in the Caribbean Sea and the

Gulf of Mexico, into the North Atlantic, there can be no doubt that the temperature of the coasts of France and Germany, of Great Britain and Scandinavia, would fall several degrees.

In the great inland seas of Europe there are likewise regular well-marked currents. Thus there is a regular and strong current from the Baltic, through the Sound, into the North Sea. From this we must conclude, that its surface does not lose by evaporation so much as it gains by the plentiful supplies which it receives from rivers. In the Mediterranean, on the other hand, to whose surface the prevailing south wind yields up a part of the heat which it has taken up from the scorching sands of the African Desert, the evaporation is so strong that the water poured in by the rivers and from the Black Sea through the Straits of Constantinople and the Dardanelles, is not enough to replace it. We find therefore a continual current setting into it all the year round from the Atlantic. It was formerly believed that there was an out-flow underneath answering to this in-flow at the surface; but later researches have shown that the two coasts forming the Straits of Gibraltar are connected by a reef of rocks reaching in many places nearly up to the surface, while the sea on both sides of the narrow channel has a very great depth. Besides, this notion is disproved by the fact that the Mediterranean has a higher temperature, both at the surface and in its depths, than is found in the neighbouring part of the ocean. To this constant influx must probably be attributed the fact, that the Mediterranean contains a somewhat larger proportion of salt than does the Atlantic, whose degree of saltness has been found to be almost exactly the same in all latitudes. For the contrary reason, the Baltic contains less salt than does the ocean.

In the Pacific Ocean, as well as in the Atlantic, a westward current is observed, which reaches, having the breadth of the whole torrid zone, from the coast of America to those of New Holland, and of the Indian Archipelago. The best known of its tributaries is the Peruvian current of cold water, which, flowing from the Antarctic Sea into the great ocean, turns in an eastward direction towards the American coast, in the latitude of Chiloe, and there separates into two branches,—a northern, and a southern. The latter flows along the coast as far as Terra del Fuego, and around Cape Horn into the Atlantic. The northern branch runs with great speed* along the coasts of Chili and Peru, and, about the equator, begins to spread itself out in a westward direction. It everywhere has a temperature strikingly low for the latitude; and this affords an explanation of the generally uniform and temperate climate of the coasts of Chili and Peru. Thus the mean temperature at Callao, the harbour of Lima, under 12° south latitude, is only 20° C. (68° F.), while, on the other hand, at Rio Janeiro, on the east coast of South America, nearly in 23° south latitude, it is 23°·2 C. (73°·76 F.) HUMBOLDT found at Callao, in the beginning of November, when the temperature of the air was 22°·7 C. (72°·86 F.), that the temperature of the sea within the current was only 15°·5 C. (59°·9 F.), while outside of the current it amounted to from 26° to 28°·5 C. (78°·8 to 83°·3 F.) Even near the equator, after the direction of the stream has become due westward, its mean temperature does not rise above 20°·5 C. (68°·9 F.) However, during its westward progress, it gradually mounts up to 27° or 28° C. (80°·6 or 82°·4 F.)

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* Favoured by this current, ships run in eight or nine days from Valparaiso to Callao, and in four or five days from Callao to Guayaquil, while they often require as many weeks for the return voyages.

At the western side of the Pacific its equatorial stream separates into several branches. Part of its waters seem to run southwards along the east coast of New Holland, a greater part pours itself through the channels of the Asiatic Archipelago into the Indian Ocean; the rest takes a north-eastward course along the Chinese Sea, washes the eastern coasts of the Japanese Islands, and then spreads its warm waters before the north-east winds over the northern part of the great ocean. Thus the Japanese current plays, in the Pacific, the part of the gulf-stream in the Atlantic, and it exerts an influence on the climate of the west coast of the opposite continent like to, but, on account of the less favourable conditions,* not so powerful as, that wrought by the gulf-stream on Europe. The following comparison shows the advantage which the west coast has over the east of North America, as well that of the west coast of Europe over both:

Place.	Latitude.	Degrees of Mean Temperature.					
		Of Winter.		Of Summer.		Of the Year.	
	Deg. | Min.	Cent.	Fahr.	Cent.	Fahr.	Cent.	Fahr.
Sitkha (Russian America)	57 „ 3	+ 0·7	32·26	12·7	54·86	7·4	45·32
Nain (Coast of Labrador)	57 „ 10	—18·5	+ 0·5	7·8	46·04	—3·6	27·68
Aberdeen	57 „ 9	+ 3·9	29·02	15·3	59·54	9·6	49·28

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* The Japanese current runs with far less strength than the gulf-stream, and its temperature is of course lower, as it is derived only from the northern limb of the equatorial current.

The eastern coast of North Asia has a considerably higher temperature than the east coast of North America under the same latitudes. The former is not, as is the latter, struck by a current coming from the Frozen Ocean, and, besides, a part of the north-east current that comes up from Japan, passes through Behring's Straits, and is felt even farther up on the north coast of America.

Besides the regular sea-streams which in general flow ever in the same direction, there are also some which are periodically reversed; that is, some which run, during one part of the year in one direction, during the rest in another. Thus, between New Guinea and the island group of the Carolinas we find a current which runs eastwards from April to October, and from October to April westwards, answering exactly to the winds which prevail during the same periods. We meet with like periodical currents in the China Seas, in the Indian Ocean, &c., &c. Their dependence upon the direction of the wind is everywhere obvious. The same is true of many irregular currents which are set up and cease again as the winds rise and fall.

The knowledge of the periodical currents is, like that of the regular streams, of great consequence to sailors. But the former have not the importance for the study of climate and of the arrangement of the heat of the earth, which, as I have before shown you, attaches to equatorial currents, and to their tributaries and offsets.

LETTER XIII.

THE WINDS.

THE winds are currents of the air exactly the same in kind as those of the waters in rivers and in the seas. Every disturbance of the balance between neighbouring masses of air, an increase of density, and consequently of pressure on the one side, or a diminution of density on the other, immediately sets up a movement from the heavier towards the lighter air; just as water is set in motion, if it suffers a greater pressure on one side than on the other. The most usual and general cause of such disturbances of the balance of the air is *unequal heating*. The causes upon which the draught of our lamps, the burning of the fuel in our fire-places, and the airing of our rooms depend, are the same as those which we find at work as the moving power of the slightest breezes and of the mightiest gales, which stir the restless air and mingle it in every climate.

I have already shown you that the air takes its heat, in the first place, chiefly from the ground; that the warmed and so expanded air rises, and that it is only in this way that the heat of the soil is spread over the higher regions of the atmosphere. Now the soil is not everywhere equally heated. The degree, in which it is favoured in this respect, depends, as you know, greatly upon the situation and latitude of the place. Besides this, certain substances have the property of absorbing more of the sun's rays than can others, supposing equal quantities of heat to fall upon both. Again, other substances allow the sun's heat to penetrate deeper; and thus from one cause or the other the soil at different places takes a different temperature. Thus during the day-time the temperature in the shade of trees, of houses, and of clouds, in moist meadows and forests, and on surfaces of water, is usually lower than on dry soils, on rocks, on roofs, and on level plains. The air which rises most quickly over the warmest spots of the soil, is replaced by air coming in from cooler places; and thus are set up those movements of the air, which we generally find on the borders of forests, in the shade of trees, at the openings of shady mountain glens, and in such valleys themselves, on the banks of rivers and lakes, and on the sea-shore.

It is impossible that the air can flow from one place to another, without being replaced by a movement in the opposite direction, for instance, by a return current in the upper regions of the atmosphere. The following experiment will clearly illustrate this. If a door be set ajar between two rooms, one of which is filled with cold air, the other with warm; and if now a lighted candle be held at the crevice, at different heights one after another; you will remark that at the bottom the flame will be turned from the cold room into the warm, at top it will be driven from the warm towards the cold room, and at some point near the middle height it will burn steadily upright. From this you will learn that there are two currents, one above the other, and in opposite directions. If a stove is brought quickly up to a strong heat in a cold room, and a piece of paper is burned over its warm surface, the smell that arises will be perceived near the coldest wall, perhaps at the window, before it reaches the middle of the chamber. If several thermometers are placed about in the room, they will show more distinctly that the heated air rises immediately to the ceiling, that it travels along this to the walls, and particularly to the windows; that there it is gradually cooled, and slowly falls till it reaches the floor, where it is often 5° or 6° C. (9° or 10° F.) colder than at the ceiling. On the floor it flows towards the stove, and there being warmed rises again as before.

Just the same process goes on in the open air, wherever neighbouring tracts of land have an unequal temperature, which they impart to the air that hangs over them. In every hot summer's day there are streams of air mounting up from such spots on the soil as are most strongly heated; these currents carry with them the moisture as well as the warmth of the ground, and they sink again over cooler places, such as surfaces of water and forests. This is well shown by the periodical *Land and Sea Breezes*, which on many coasts blow from the sea to the land by day, and by night from land to sea. If the land is more heated than the sea during the day, the air that is over the land will mount upwards, and the cool sea air will flow into its place; the air getting cooled in the upper regions falls down again over the sea. During the night, the land is more cooled than the surface of the water; the latter at last becoming warmer, the air flows from the land to the sea, while the sea air, now becoming lighter, mounts upwards.

Dove compares this circulation to the turning of a wheel. If the temperature is equal, it stands still; if it become unequal, it turns, first towards one side then towards the other. Twice daily it stands still, when one of these movements is passing into the other.

Land and sea breezes occur in high latitudes only during the summer months; in tropical climates, however, they follow with the greatest regularity, and become of high importance to shipping. The sea breeze springs up in the morning some time after sunrise, increases in strength till about two or three o'clock in the afternoon, and then gradually falls off. About the time of sunset a perfect calm prevails. Soon after the land wind gets up, and blows with gradually increasing strength through the greatest part of the night, and begins to lull towards morning.

These alternating air currents appear on all coasts within the tropics, even on those of the smallest islands, and they occur every day with perfect regularity, unless they are masked or turned from their true direction by other more powerful winds. The land and sea breezes are, for the most part, felt only at a small distance from the shore. On some far-stretching coasts, however, such as that of Peru, their influence reaches a great distance out to sea.

In the hottest zone of our earth an uninterrupted current of warm air rises from over land and sea, and must be replaced from below; and thus a movement of colder air sets in from higher latitudes on both sides towards the equator. The air, that has mounted up, now flows back in the higher regions of the atmosphere on both sides towards the poles, and falling, as it is gradually cooled in its progress, reaches the earth again in the middle or higher latitudes. This is a circulation of the same kind as that presented on a far smaller scale by the land and sea breezes.

In the torrid zone, then, we find in the lower layers of the atmosphere, on both sides of the equator, polar winds—blowing from the poles to the equator—north winds in the northern hemisphere, and south winds in the southern, both of which, however, for a reason which I shall presently explain, take a more and more westward direction as they approach the equator. These are called the *Trade-winds.*

In the higher layers of the atmosphere, equatorial winds prevail,—winds whose general direction is from the equator to the poles,—which however take a more and more westerly direction as they progress. These are called the *Upper or Returning Trade-winds.*

Where the lower trade-winds of the northern and southern hemispheres meet, a region lies, in which there blows only a slight east wind, which, however, often lulls altogether, and is sometimes changed for the most violent storms. This is the *Region of Calms* so much dreaded by sailors. In this belt, the hottest of the earth, the currents of air that flow from the poles, becoming continually warmer, do not come down lower than at least twenty thousand feet above the surface, for no traveller even on the highest peaks of the Andes has ever got into the upper trade-wind. However, that it is blowing there we know from the little white clouds, which are sometimes seen at great heights coming up, as it were, against the lower trade wind. Several times, too, more distinct evidence of them has been obtained from the ashes, which they have carried with them immediately after volcanic discharges. Thus, on the occasion of the outburst of Cosiguina, which I have before mentioned, as taking place on the 20th of January 1835, the ashes were borne in a north-easterly direction as far as Jamaica, and at the same time were driven in a south-westerly direction into the Pacific Ocean, where at a distance of about nine hundred and sixty miles from the volcano, the Ship 'Conway' fell in with a shower of ashes. Hence, the ashes were carried by the rising current of air partly in a northerly, and partly in a southerly direction.

At the limits of the torrid zone the upper trade-wind blows very much lower; it is found, for instance, on the Peak of Teneriffe even in summer. Beyond the tropics it comes gradually lower, reaching the surface in summer in somewhat higher latitudes than in winter, and appears as the south-west wind so prevalent in the temperate zone.

The trade-winds, and, indeed, especially those of the Atlantic Ocean, have been known, as we learn from the history of the discovery of America, since the first voyage of Columbus. Their long continuance caused much fear to the Spanish sailors, who believed that this everlasting east-wind would render their return to Europe very difficult. The illustrious astronomer Halley, as early as the year 1685, gave a satisfactory explanation of them, by proving, that the currents of air, as far as regards their main directions, from north to south, and from south to north, could only blow, on an earth at rest, in lines parallel to the meridians, but that these directions must suffer a very considerable change from the turning of the earth round its axis. The speed with which any point on the surface of the earth moves round, is greater or less according to the size of the circle of latitude in which it lies. It increases from the poles, where it is nothing, to the equator, where it is greatest, amounting there to fourteen hundred and twenty-seven feet in a second.

In time of calm the air has no other motion than that which it shares with other earthly bodies; it is moving round with the speed of the place at which it lies. If, however, the wind blows,—that is, if the air have another motion besides that which belongs to it as a part of the earth,—it can keep its direction unchanged in spite of the rotation of the earth only in one case. And this is when the wind is exactly due east or due west, or in other words, when its course does not vary from the parallel of latitude from which it starts; because this is the only case in which any point of the surface, at which the current arrives, has exactly the same rate of motion round the earth as any which it has left.

But, if the wind blows from the pole towards the equator, it will be always passing from places moving with less, to places moving with greater speed. For instance, the speed of revolution of any point on the earth's surface under the thirtieth degree of latitude, is twelve hundred and twenty-nine feet in a second; under the twenty-ninth degree it amounts to thirteen feet more; and under the twenty-eighth, to twenty-nine feet more in a second. Air, therefore, which moves from the thirtieth to the twenty-ninth parallel, keeps its original rate of revolution—that due to the thirtieth degree—and, therefore, when it reaches the twenty-ninth degree, is still turning, it is true, in the same direction as the earth; that is, from west to east, but is moving round eastwards more slowly than the earth below it, by thirteen feet in each second,—and, when it reaches the twenty-eighth degree, twenty-five feet in each second, more slowly than the ground. It must seem, therefore, to an observer, who feels this lagging behind of the wind as an actual resistance—and its effect upon all bodies which share the movement of the earth is the same—to blow in the opposite direction, namely, from east to west. The rate of motion in the westward direction, which the wind acquires in this manner, is certainly very much diminished by the manifold resistances which it meets with from the earth's surface; and therefore the lower trade-wind seldom has a greater speed than fifteen feet per second. Nevertheless the original polar direction must pass more into a *westward* one (that is, the wind must become more *easterly*), the greater the difference of the latitude of the place, from which the wind began its movement towards the equator, from that of the spot at which it is observed.

From this you will readily understand why the currents which start at the northern hemisphere as northerly winds, must, as they advance southwards, pass gradually through a north-easterly direction into one more nearly from the east; and why, again, in the southern hemisphere, the winds which in like manner set out from the south must become first south-easterly, and then more and more easterly, in their progress northwards.

Currents of air, which flow in the direction from the equator to the poles, must behave in an exactly contrary manner. They come from regions moving with greater speed round the earth's axis—a speed which they share themselves—to higher latitudes; that is, to regions moving round at a slower rate; and must, therefore, the farther they get from the place of their origin, more and more outrun the ground in its motion from west to east. Hence, wherever these winds are met with, they seem to blow from the westerly points of the compass.

Thus, in the northern hemisphere, a southerly wind always becomes in its progress, first, a south-west, and at last, a westerly current.

In the southern hemisphere a northerly wind passes gradually through a north-west into a west wind.

This explains why between the tropics an east wind, and why in higher latitudes, especially where the return trade-wind has fallen to the surface, west winds are always prevalent, although the former set out at first as polar, and the latter as equatorial currents. These west winds, since they arise in the upper regions, where they can meet with but very little resistance, have therefore commonly a much greater speed than the east winds, which are met with only in the lower layers of the air.

The trade-winds of the Atlantic Ocean are the most thoroughly known by sailors. They extend on both sides of the equator, several degrees beyond the tropics. The north-east trade-wind blows between 9° and 27° north latitude; however, its northern, as well as its southern, limit pushes out two or three degrees in summer, and in winter retreats a little within the latitudes I have mentioned. Accordingly, the summer limit of the north-east trade-wind lies somewhat to the north of the Canary Isles, and in America embraces the states of Florida and Georgia.

The south-east trade-wind prevails between 3° north latitude and 25° south latitude, with, however, certain changes due to the position of the sun. And the belt of the calms lying between the north-east and south-east trade-wind, and having a breadth of five or six degrees of latitude, does not always remain in exactly the same place, but in summer advances towards the north, and retreats in winter; always, however, in the Atlantic Ocean, keeping to the north of the equator.

The trade-winds set out from the middle of Africa, and extend, probably in consequence of the great masses of land and the hot sand-deserts of Northern Africa, as well as by reason of the warm waters of the Atlantic equatorial current, farther on the north than on the south side of the equator. Over the continent of South America they may be traced as far as the chain of the Andes.

The trade-winds of the great ocean are first felt at a considerable distance from the American coasts, from which they blow regularly the whole year round, on the north of the equator to the

Philippines, and on the south to the coasts of New Holland. They are more uniformly arranged on the two sides of the equator than the "trades" of the Atlantic, but, like the latter, they have between them a region of calms, of which the mean limits lie a couple of degrees each north and south respectively of the equator.

Over the Indian Ocean, south of the equator, between New Holland and South Africa, the south-east trade-wind blows with the same regularity as on the two other great seas. But in the northern parts of this ocean we find the north-east trade-wind, which is there called the *North-east Monsoon*, blowing only in winter, between the months of October and April, while from April to October the wind sets with equal constancy in the opposite direction: this latter is called the *South-west Monsoon*. These two winds pass into each other in autumn and winter, through an interval of calms, which alternate with furious hurricanes.

The cause of these half-yearly changes lies in the peculiar arrangement of the land and water in that part of the earth. The Indian Ocean is, as you know, bounded only on the north by land, which for the most part extends far into the torrid zone, and which must therefore acquire during summer a far higher temperature than the neighbouring sea, although the latter lies nearer the equator. The main direction of the current of air during the summer is, therefore, towards the north, and thus it is converted, by the slower motion of the northern parts round the earth's axis, into a south-west wind. During the winter the sea has the advantage in temperature; and so, again, the relations of the Indian Ocean at this season, as regards wind, form no exception to the universal rule.

Our knowledge of the laws of winds had made very little progress from the time of HALLEY till within the last twenty years, during which the labours of DOVE and of REID have placed the theory of the winds on an entirely new footing.

By a long course of laborious researches, DOVE was led to what he called the Law of Rotation; in establishing this law he showed that the trade-winds, and the entangled relations of the winds of the temperate and frigid zones, are but the necessary and simple results of the same physical conditions.

If an observer is stationed at a spot, in the northern hemisphere, close to the place where the excitement of the wind begins, where, for instance, currents of warm air are mounting up from the heated soil; and if by this agency a current is made to set in from the north, he will see the wind-vane settle itself at first in the direction of due north and south. If, however the cause of this motion of the air continues to act, the air of higher latitudes must share more and more in the effects. The air coming as it does to the place of observation from distances continually greater, that is, farther and farther north, must have a movement in the direction round the earth, that is continually slower and slower, and must therefore gradually take a more and more westward or easterly direction. If therefore the cause of the original north wind remains at work, the wind-vane must gradually pass from a north direction through north-east to east.

A wind which at its commencement at the place of observation appeared as a due south wind, draws the air, if it lasts, from latitudes nearer and nearer to the equator, and must therefore gradually pass through south-west into west.

If the north wind has passed by degrees into an east, or the south wind into a west, it must very soon, in consequence of the resistance of the ground, lose that motion which the ground has not in common with it, and must take the rate of motion round the earth which the ground has at the latitude, at which it is at the time, that is to say, a calm ensues.

If, however, the cause which first set up the current continues, the same set of effects as occurred at first must be repeated; that is, the east wind must, after the lull, become a north wind, which again gradually passes through north-east into east. In like manner the west wind will be reconverted by the calm into a south wind, which again will gradually turn round to west.

If, therefore, polar and equatorial currents are alternating with each other in the northern hemisphere, the mean direction of the wind will travel round the compass through south, west, north, east, south, and the changes will take place oftener between south and west, or between north and east, than between west and north, or east and south; since the first changes show only a continuance of the exciting cause, while the latter point to a change of it.

By a like course of reasoning, we are led at once to the conclusion, that, when in the southern hemisphere polar currents alternate with equatorial, the mean direction of the wind will be successively south, east, north, west, south, and that the changes ensue oftener between north and west, or south and east, than between west and south, or east and north.

The trade-winds form but a particular and, indeed, most simple case of this general behaviour. The cause to which they owe their origin is most active in the belt of the calms, where the influence of the tropical sun is always raising currents of warm air and vapour. The uninterrupted continuance of this action gives rise to streams of air constantly setting in from north and south. These two polar currents take a direction more and more easterly (westward), and, at the place of original influence, namely, in the belt of the calms, a due easterly direction; for here slight breezes from the east alternate with calms, just as is required by the law of rotation.

Dove has brought together a great number of observations, made in different parts of the world, in proof of the universal truth of this law. It may now be considered as established, that in the temperate, and probably also in the frigid zones, where southern currents are continually alternating with northern, the wind runs round the compass turning generally in one certain direction; and that, in the northern hemisphere, the direction of this veering round is generally the contrary to that which prevails in the southern hemisphere.

LETTER XIV.

THE WINDS, CONTINUED: THEIR INFLUENCE ON CLIMATE.

If two winds are blowing in opposite directions one above the other, or near to each other, there must lie between them a layer of air at rest, which passes gradually on each side into the motion of the two currents.* If one wind is stronger than the other, it will by degrees draw the air that was at rest into its own movement; part of the opposite weaker stream will come to rest, and will then in like manner be dragged into the motion of the stronger current, and thus the weaker will gradually give place to the stronger. Thus, for instance, the south-west wind of the upper regions that is retreating from the tropics, displaces, where its current is strongest, the north-east current that blows along the surface, and thus gradually comes down to the earth as the prevailing wind of the lower regions; and just in the same manner, a north and a south wind blowing near each other side by side, may be alternately swallowed up by each other.

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* You will remember the experiment of the open door, and the behaviour of the candle-flames.

In the Northern Atlantic and Pacific Oceans, the south-west wind is by far the most powerful, not only in the upper regions, but also at the surface of the earth. The same currents are felt to a certain distance from the coast, sometimes more, sometimes less, over the mainland of the continents. However, it is clear that the air cannot be flowing towards the north at the same time under all meridians. If, therefore, a south-west current prevails in certain parts, a north-east wind must be blowing somewhere near it.

In the west of Europe, the south-west wind is, as you know, the most prevalent. It is the upper trade-wind of the Atlantic, which in summer comes up to northwards of the Canary Isles, and in winter, when the lower "trade" retreats with the sun, comes down to the level of the sea, farther and farther south, and then in part turns back again southwards, and in part pursues its northern course over the earth's surface. The balance must be maintained by a north-east wind prevailing over the east of Europe and the north of Asia; and this, during its continual struggle with the south-west current of the Atlantic, must be sometimes displaced by it, and sometimes must in turn push itself to the far west of Europe. We have not as yet learned enough of the conditions concerned to enable us to account satisfactorily for this frequent change of the direction of the wind over all parts of Europe.

During the strife of two winds blowing near each other in contrary directions, the layer of air between them cannot be drawn into the motion of the more powerful current, without first suffering a certain amount of condensation. Hence there arises, together with the onward motion in the direction of the current, a sideward movement of the condensed air in a direction at right angles to the former; in other words, the air that is just outside the current, and that was before either actually or relatively at rest, or perhaps even moving in the opposite direction, flows into the current with a speed that is greater the more it had been condensed before, that is, the greater the resistance it offered before it could be swept away into the stream. But now the side-current, thus set up, itself exerts a like action. It condenses the air that lies before it, and that was already engaged in the main-stream, though at rest, relatively to the side-currents; it thus becomes continually turned from its course, and always in the same direction, and must, therefore, take a twisting or whirling motion. Thus *whirlwinds* always arise where winds are forced by any cause to blow towards each other in opposite directions, or where high winds sweep past columns of air shut in between, for instance, walls, houses, or mountains. If the air that is thus at rest, or relatively at rest, is on the right hand side of a person facing the current, it will take a twisting motion in a direction contrary to that of the hands of a watch lying on its back. If, however, the still air be on the left of the stream, it will begin to turn in the same direction as the watch-hands.

Storms are whirlwinds moving onwards in a certain direction. The violence of their twisting motion is the greater, the more the main current that gives rise to them has to struggle with resistances, and being stopped by them, is turned from its original course. But contrary winds are not the only resistances of this kind, such are also presented by lofty mountain chains.

The *hurricanes* or *tornados* of the West Indies, so well known for their frightful fury, arise where the belt of the trade-winds passes into that of the calms. They may be set up—either by an encroachment of the south-east trade-wind, which, after it has passed the equator, gradually strives to take a south-westerly direction in the zone of the north-east "trades,"—or by a falling or forcible descent of the upper or return trade-wind into the region of the lower. The south-west current established by one means or the other, while it seeks to press itself into the north-east "trade," is turned by the resistance of the latter from its own direction towards the north-east, and forced to strike across the West-Indian Sea. So long as it remains within the trade-region, the whirlwind proceeding in this direction takes its onward course almost in a straight line; as soon, however, as it passes the limit of the trade-wind, and gets into the region of the south-west wind, its course bends suddenly round towards the north-east, it spreads itself out, and loses much of its violence, because the resistance opposed to its passage towards the north-east, namely, the contrary north-east trade-wind, is now withdrawn.

The whirlwinds in the East Indian Seas, which occur when the north-east monsoon is passing into the south-west monsoon, as well as the *Tyfoons* of the China Sea, owe their origin and direction to similar conditions.

In Western Europe the storms come generally from the south-west, and arise from the struggle of a powerful south-west current with that setting from the north-east. From the manner in which tempests are raised, the reason is clear why, during a storm, the wind-vane may be carried round to every point of the compass, why violent blasts may be followed by sudden calms, and why the wind may then blow again from the opposite quarter. By close attention it may be remarked, that the motions of the vane are not without a law, but that, if it stands, for instance, on the south-east side of the advancing whirl, it shows the direction of the wind to be successively north, north-west, west, and south-west, just as, according to what I have been explaining to you, occurs in the formation of a whirlwind; but in a direction opposite to the course of turning, which in the common changes of the wind is required by DOVE's Law of Rotation.

You know what frightful force is exerted by storms. We often hear of trees being dragged up by the roots, of houses being shaken, of tiles and chimney-pots torn off, and even of whole roofs lifted from their places, and carried sometimes to a distance. But the most violent storms are encountered by sailors, and by those who live near sea-coasts, because over the sea the air-current meets with the fewest hindrances to check its action Indeed there are many instances, and especially in the tropics, of whole islands and large tracts of coast, being laid waste by the fury of hurricanes, and even of their being overwhelmed by the sea,—thousands of houses having been swept away or thrown down by the deluge of waves, and numbers of human beings buried in their ruins.

This force of storms is accounted for by the vast swiftness of their progress. It has been found, by comparing different observations, that hurricanes march on sometimes at the rate of from forty to forty-eight miles an hour, that is, of from sixty to eighty feet in a second. The swiftness of their whirling motion must, however, be far greater. We have not as yet found any sure means of measuring this rate, but it cannot be doubted that it amounts sometimes to a hundred and fifty feet in a second. But so swift a motion of the air as this, when it meets with any obstacle, exerts upon it a pressure of about thirty-two pounds on the square foot. The force with which the wind strikes bodies that meet it with their full front, may be easily reckoned from this. The resistances at the surface of the earth, while they receive the pressure of the wind, gradually lessen its speed. At great heights, where it meets with none of these checks, for instance on the peaks of lofty mountains, we almost always find the force of the wind far greater than below.

The air above, therefore, is always outrunning that below it in its onward progress, and thus it happens that changes in the direction of the wind, and the commencement of storms are often felt on high mountains several hours, and even days before they reach the lower ground. It is commonly remarked, in countries where in winter the thaws are brought by the south-west wind, that they begin to take effect first in the high-lying districts.

From the greater speed of the wind in the higher regions there results a diminution of the density, and, therefore, of the downward pressure of the air, for the same reason that in swift rivers and brooks the surface of the water sinks slightly from the banks to the line of quickest flow. One immediate and constant result, therefore, of strong currents in the upper regions of the air, by reason of the constant endeavour to maintain the balance of forces, is the sucking or lifting up of the lower layers of the atmosphere.

It is in consequence of this that we so often see light particles of dust and water, whirled up from the earth during high winds and storms.

The winds are the most effective agents in equalizing the temperature of the surface of the earth. Wherever they come in contact with the earth they take the temperature which they find there, and carry it with them to other regions. Thus the polar currents, the air that flows from higher to lower latitudes, bring coolness to the torrid zone, while the returning trade-winds, when they come down to the earth again in higher latitudes, set down there a part of the warmth which they have brought from the hotter belt of the earth.

With regard especially to the northern hemisphere, which is most inhabited, it is clear that in every part of it where northerly (north, north-east, and north-west,) winds, taking the average of the year, generally prevail, the mean temperature must be lowered, and that, on the contrary, in countries where the south wind is most prevalent, the mean temperature must be found higher, than could result from the direct influence of the sun's rays alone.

That the countries forming the western borders of Europe and of North America have generally a higher mean temperature than is found on the east coasts of North America and of Asia, is a result of the prevailing south-west wind, which carries the warmth of the sea over the neighbouring coastlands.

The coasts of Europe are especially favoured in this respect by the comparatively high temperature, which the Atlantic has even up to the Arctic Circle. The variations of the warmth of the sea during the course of the year being but small, all these countries must share the peculiarities of the sea climate. The winters are milder, the summers less hot, and the fall of moisture from the air more plentiful than in the inland parts, and on the eastern coasts of the continent.

The air which rises from over the sea, in the hottest zone of the earth, is fully charged with moisture. During its progress northwards, its capacity for vapour, that is, its power of retaining the whole quantity of vapour taken up, is lessened, it is, therefore, always losing some of its charge of vapour and continually letting it fall in the form of water. Hence come the rains which, in some parts of Europe, often last for days and weeks; these soften the cold of winter, and bring coolness in summer, because the thick layer of clouds, from which they fall, weakens the direct action of the sun.

The air from the south, when it has come down into the lower regions, and is passing over the sea, cannot be far from its dew point (the point of full charge of moisture). But as it passes farther up over the continents, its charge of water is lessened, and it becomes less able to recover, by fresh supplies of water, its losses by the continual fall. The south-west winds, therefore, if they reach as far as the inner parts of the continents, bring usually but little moisture thither. But in the east of Europe, and in the midland parts of Asia, as I have already told you, north-east winds prevail. They carry the cold of the north to lower latitudes, and are, therefore, probably the chief, if not the only, causes of the low mean temperature of Russia and Siberia. This northern current, as it gradually moves onward into lower latitudes, is continually gaining in temperature, and consequently in capacity for vapour. It becomes a drying wind, and by keeping the sky clear during the long summer days, allows the heat to increase; but on the other hand, during the long winter nights, when radiation is going on, it aids powerfully in the cooling of the ground. In the west of Europe, too, we remark that severe cold in winter and the dry heat of summer are brought by gentle, cool breezes, especially from the north-east.

Dove made the following remarks on this subject:—When we observe that the south-west wind gradually passes through west, north-west, and north to north-east, we may conclude that a rainy season, perhaps of long continuance, is at last over. If it is summer, the fine weather begins; but in winter a period of frost, until after a shorter or longer time the south-west wind again comes down from above, and recovers the mastery. If this takes place gradually, that is, without the occurrence of storms, the wind-vane changes back, occasionally shifting to and fro, and sometimes veering steadily round, through east, south-east, and south to south-west.

The especial influence of the moist and warm south-west winds is felt in the plains of middle Europe, in Eastern Prussia and in Poland. In the south and south-east of Germany they are sooner robbed of their warmth and moisture by the lofty mountain ranges which they have to pass. The peculiarities, then, of the continental climate come out more strikingly in Bohemia and Austria than in the rest of Germany. To the Scandinavian mountains, which run between Norway and Sweden from the farthest north of Europe, a still more remarkable contrast between the condition of these two countries, as regards climate, is owing. For, while the sea-climate prevails throughout the whole of Norway up to the North Cape, the north of Sweden, and of Lapland particularly, presents all the marks of the continental climate —colder winters, warmer summers, and greater dryness of the air.

Similar conditions hold good in North America. A mighty chain of mountains, many of whose peaks reach above the snow-level, runs from the Arctic Sea on the west side of the Mackenzie river, and through seven or eight degrees of latitude, almost along the coast of the Pacific. This range arrests altogether the proper influence of the sea-air; and this explains why the western slopes of the Rocky Mountains, down to the sea-coast, have far less difference between their extremes of temperature, and a higher mean, than the east of North America enjoys. It is true that west and south-west winds blow regularly quite across to the eastern coasts, but they must yield up their charges of heat and moisture on the high crests of the mountains, and they are therefore generally dry, bringing with them only the temperature of the wide tracts of country over which they pass. In Canada, therefore, and in the United States, with the exception of the southern districts, so far as they are under the influence of the trade-winds and of the gulf-stream, we always find hot summers and very cold winters. However, the condition of the high north has a considerable share in producing the cold of the latter, and the generally lower mean temperature of America, north of 35° north latitude, and eastward of the Rocky Mountains.

The whole coast of Labrador and of East Main, on the west of the chain of hills which separate the waters that run into the River and Gulf of St. Lawrence from the water-shed of Hudson's Bay, is a desert surface of rocks and lakes, with a very little useful soil at some few spots, and a small growth of dwarf wood. We only meet with arable land and tillage on the south-east side of this highland, towards the St. Lawrence and the Atlantic. The inland country north of the great lakes, and towards the Rocky Mountains, is hilly, and crossed by great river-valleys, capable of culture and clothed with forests. But the slope of this highland towards the Frozen Sea and towards Hudson's Bay, forms only a dry plain without arable land, and with scarcely any herbage. Hardly any plants but the numerous mosses grow, and trees are not to be seen, The north-wind sweeps as unchecked over this cheerless waste, as it does over the frozen lakes and seas, carrying cold and dryness to the south.

We can now without difficulty explain why the lowest mean yearly temperature, and the coldest winters, must be found especially in the inland parts of continents, why their position with regard to the sea, and the direction of their winds, have almost as much effect upon the climate of the countries in the far north, as the slanting direction of the sun's rays, and the length of its winter absence. It is clear, too, that in the coldest regions of the earth every wind must bring warmth with it, and that the severest cold can only occur when the air is still.

LETTER XV.

THE MOISTURE OF THE AIR, AND THE FALL OF WET.

Moisture is, as you know, next to heat, a condition the most necessary to the thriving, and even to the life, of plants, and therefore to the fitness of a country for the dwelling of man. Plants are dried up, and their growth stopped, if moisture fails in summer. The smiling fields of Dauphiny, clothed with the loveliest green in spring, and the plains of Southern Italy and of Greece, after being without rain for months in summer, are changed for the most part into dry sandy flats. In many hot regions where water is either quite or nearly wanting, the soil is unfruitful, just as in the high north, and almost devoid of herbage. Such is the state of the vast tracts known as the Desert of Sahara, and of great part of Arabia and Persia.

Springs and rivers can only supply the water required for the nourishment of plants at particular spots, and that constantly, as a general rule, only near high mountain-chains. Thus Lombardy owes its uncommon fruitfulness chiefly to the industrious care, which the inhabitants have been taking for centuries, to spread the water from the Alps over the whole face of the land. The fertility of the desert-bounded valley of the Nile depends only on the overflowing of the river. And the flourishing appearance of those single spots—the Oases—in the midst of the deserts of Africa and Arabia, is due to the springs which gush forth within them. There are instances too, some of which I have already mentioned to you, of industrious people having won for their land a productive power, which nature seems to have denied to it, by artificially opening springs and pouring them upon their soil.

All these, however, are, as I have said, but single and partial results. The most universal and active source of the water necessary for the growth of plants is the moisture of the air, the water, which the air carries with it in greater or less quantity as vapour.

You know the property which water has of evaporation. Water left to itself in open vessels, and cut off from all supplies from without, lessens gradually in bulk, and at last vanishes altogether; wetted bodies placed in the open air become dry. The moisture that has come in winter and spring always disappears when we have had fine weather for some time in the warm season. The stones wetted by a summer shower, the plants covered with the morning dew, generally become dry soon after the sun has begun to shine. All this water is dissipated into the air; it evaporates, that is, it passes into the state of vapour.

Evaporation does not always take place with the same quickness. You cannot fail to have remarked that it is closely connected with heat and with the draft of air. The property of air, of taking up vapour into the space which it occupies itself—its capacity for vapour—increases with the temperature; for this reason evaporation is favoured more by warm than by cold air. But in all cases the amount of vapour, which a given bulk of air can take up at a given temperature, is limited. If the limits of this capacity are reached, evaporation ceases, until the air thus charged with moisture is removed, and other drier air takes its place. The free air of the atmosphere is probably never quite dry, but it seldom holds as much moisture as it could take up at the temperature at which it is. For this reason a draft of air favours evaporation, and that the more effectually, the drier and the warmer it is. Moist air cannot aid the formation of vapour, however swiftly it may move. The air is commonly moister and stiller over low lying spots than on heights. You will now quite understand why it is necessary to seek high places, if the object is to obtain the quickest evaporation in the open air.

Air, which at any time contains as much vapour as at its then present temperature it can take up, is said to be saturated or fully charged with water-vapour. It is said, for instance, to be half charged if it holds fifty per cent, or three-quarters charged if seventy-five per cent, of the greatest amount of moisture that it can take up at its actual temperature. The degree of charge always shows, therefore, not the actual, but only the relative quantity of vapour held in the air. Thus in the cold season of the year, when it contains but a small actual amount of water, the air may be, and in fact generally is, moister, or nearer to its point of full charge, than in summer, when it holds a far greater quantity of vapour. In the latter case, indeed, evaporation may perhaps be still briskly going on, while in the former it will have almost ceased. Thus in the months of November and December the air generally seems to us moister than on a warm day in July, when, however, it will often contain two or three times as much water.

Over the great oceans the air is generally, at all seasons of the year, and in all latitudes, near its full-charge point. Over the land its condition as to moisture depends essentially on that of the ground, on the direction of the wind, and on the distance from the sea.

All bodies, without exception, have the power, some more, some less, of taking from the air some of its moisture. Many substances—for instance, burnt lime—have this property in so high a degree that they can be made use of to dry the air completely. With the greatest number of bodies, and among these, with plants, the power of sucking up this water adjusts itself to the relative condition as to moisture, or to the degree of water-charge of the air. In very moist air, and this whatever the temperature may be, such substances take up the greatest amount of water that their peculiar property will allow at the given temperature,—they become fully charged with moisture. If the moistness of the air is removed from the point of full charge, the bodies that are in it lose some of the water which they contain; they begin to become dry, and this goes on until the power with which they absorb moisture—a power which, in all bodies, is the more active the more the store of water which they have condensed from the air is lessened—is balanced by the tendency, of the water which they still retain, to evaporate.

If, for instance, the air contains three-quarters of its possible water-charge, any bodies around which it plays will keep more water condensed than when the air is only half charged. Only in very dry air, and that whether its temperature be high or low, all the water which a body has taken up will be drawn off from it.

Atmospheric air, which in a warm day seems dry, approaches its point of full-charge during the radiation of the night. Thus it is that plants, without any fall of wet taking place, but only by virtue of the peculiar power with which nature has endowed them, take up again in the night a part of the moisture which they have lost during the day. In the neighbourhood of great masses of water, on the banks of rivers, on the coasts of seas, where a brisk evaporation is always going on, the herbage, even when there is no rain, cannot become wholly dried up, while in inland districts, the want of rain is very quickly felt on account of the increasing dryness of the air which surrounds the plants.

If the air is by any cause cooled down below that temperature, at which the moisture, which it holds, will be its full charge, a part of its vapour will be withdrawn from it in the form of liquid water. Thus we see that cold bodies placed in the open air very often become studded with drops of water—*Dew-drops*—because they cool down the surrounding air to a temperature below its point of full charge, which is called the *Dew-point*. For the same reason, when it is cold out of doors, the windows of rooms which are dwelt in, and which are therefore usually filled with moist air, become wet. On cold winter days the moisture thus set down from the air hardens into ice. We then say the windows are frozen. It is clear that the windows in chambers into which the outer air can always enter freely, or whose atmosphere contains no more vapour than does the outer air, cannot become frozen.

In enclosed buildings, in which much water is evaporated, or which, being continually dwelt in, are guarded from the quick entrance of the air without, even the walls become covered with wet if the cold weather lasts for a long time. You have seen upon such walls the damp which people commonly believe to be a sweat oozing from them. In fact, however, it no more comes out of the walls than that which settles on the window-panes comes out of the glass. In both cases indeed the same cause is at work. You will find that such parts of walls are especially liable to damp as are least open to the warmth of the room; for instance, those near the floor in the corners, behind the furniture, &c.; and such walls as are most quickly cooled by outward influences; such, therefore, as have but little thickness, and are built of materials that are good conductors of heat, especially when they are outside walls and exposed to the north. There is no more sure remedy for damp on walls, and for the mouldiness to which it so often gives rise, than a frequent change of the air, which should, if possible, be warm, as it will then be drier.

When in winter the ground is cooled down below 0° C. (32° F.), water poured upon it freezes. So if a sudden south wind brings, at such time, a fall of rain, it freezes on the surface, forming a thin film or varnish of very slippery ice. But even when it does not rain, the cold ground withdraws from the warm moist air of the south a part of its charge of vapour, and covers itself with a similar thin film of ice. This ice is even formed on the floors of houses, if the cold has already found its way into them. You see that the origin of this surface ice is the same as that of the frost on the windows.

When the nights are cool, but not cold enough to freeze, most bodies in the open air, plants especially, become covered with those drops of water which we call *Dew*. It was formerly believed that dew came out of the earth.

However, WELLS, a Scotch naturalist, proved most clearly that dew is set down from the air. The temperature of many, perhaps all bodies, placed in the open air after sunset, soon falls below that of the air, and, under favourable circumstances, even below the dew-point. Now from this moment they behave like any cold body plunged in moist air; they become studded with drops of water. The degree, to which this cooling is carried, depends upon the power which the substances have of radiating heat. Those bodies, therefore, which are the best radiators, such as plants, leaves of trees, and especially grass, are the first to become covered with dew; after them come stones, the soil, and, last of all, metals, which we often see free from dew, when the leaves are already covered with large drops. Dew is formed most readily and plentifully in cloudless, starry nights, because under these conditions the cooling and radiation goes on more quickly than when the sky is clouded. You must long ago have remarked that the brightest nights are proportionally the coolest; and that when the sky is clear the contrast between the temperature of day and night is greatest. Even our hair and woollen garments are liable to become bedewed under the sky of a cloudless night; but a simple roof of leaves, or an open tent, very effectually checks radiation, and so lessens both the cooling and the fall of dew. For the same reason that side of leaves which is turned towards the open sky, is always first and and most plentifully wetted with dew.

Gentle movements of the air are favourable to the settlement of dew, because they remove the cold layers of air, which have been already robbed of their moisture, and replace them by fresh supplies warmer and richer in water. But during strong winds the formation of dew is interrupted, since the quick exchange, of the cooled for the warmer air, brings more warmth to the bodies that are chilled by radiation, and thus checks or prevents the fall of the temperature below the dew-point.

During the short nights of the early summer in the inland parts of Germany, the temperature seldom falls below the dew-point of the air. But as soon as the nights begin to increase in length towards the end of July, and still more in August and September, there is never a cloudless night without a plentiful fall of dew. In October, radiation often cools our soil even down to 0° C. (32° F.); the vapour set down by the air then solidifies; and we have *hoar frost.* You will often see, a short time before the winter sets in, and at the beginning of spring, the grass in meadows covered with rime—a proof of the strong radiating power of the grass—while the temperature has fallen nowhere else below the freezing-point.

Under the clear skies of the Tropics, the fall of dew is often so plentiful that its effect is almost like that of a smart shower of rain.

The settlements of moisture from the air, of which I have been treating, are brought on only by means, and on the surface, of solid bodies which are surrounded by the air. If a large mass of the air is cooled down throughout, below the dew-point, the water that is withdrawn from it does not generally run together into drops, but forms little bubbles (vapour-vesicles or cloud-bubbles), which float in the air like those of soap-water, containing, within their thin bulbs, air fully charged with moisture. Such is the so-called visible steam or vapour, which rises from hot water, or which is formed in the air we breathe out from our lungs, when the weather is cold and moist. When the weather is warm and the air dry, the breath forms no clouds before the mouth, because the mixture of the moist outbreathed air with that of the dry atmosphere, is not cooled down below its dew-point. And if any visible mist should be formed under such conditions, it immediately vanishes again; that is, it returns to the proper state of true vapour as soon as it is mixed with the quantity of air that has enough capacity for vapour to take it back to the state of gas.

The vapours that float over rivers in cool evenings are due to the same cause. It has always been found, that when these occur the temperature of the water is higher than that of the air that lies over it. By the same cause we account for the morning mists which float over moist ground, over meadows and wooded mountain slopes. When seen from a distance, such masses of cloud seem to be at rest. However, the process that is actually going on is exactly the same as that which attends the evaporation of water from any vessel. The vapours as they rise are first partly condensed into mist, and are then dissolved again on mixture with a farther quantity of air. In dry warm air the vapours do not become visible at all, although the evaporating process is going on more quickly than ever. If, however, the air is already moist, the mist is formed in dense masses, and spreads to a considerable distance. When, therefore, we see mists hanging over the tops of hills, and continually increasing in bulk, we conclude that we shall soon have rainy weather.

In Germany mists are formed plentifully in spring, but most so in autumn, when the cool nights, following warm days favourable to evaporation, bring on a general cooling of the air below the dew-point. This withdrawal of the moisture from the air in the form of cloud-bubbles, and the running together of these into real drops, which then quickly fall by reason of their greater weight, takes place the more perfectly, the sharper the cooling has been during the night. But that this cooling by radiation may go on briskly, it is necessary that the air be very pure, and free from vapours in the higher regions, which in Germany occurs chiefly with a north-east wind. There then it would be concluded from the formation of such morning mists that there will be a continuance of fine weather. When the nightly cooling in autumn is but slight, this is generally the result of the atmosphere being already more or less bedimmed with vapour. The south-west wind has perhaps already set in in the upper regions, while the weather-vane is still pointing eastwards. As the upper wind increases in strength it gradually draws the lower current with it, and so the air below is mixed with the atmosphere above. Thus the light mists formed by slight cooling during the night are carried up into the upper regions.

Hence the mounting up of the morning mist, especially when the barometer falls at the same time, is rightly considered as foreboding rainy weather.

The *Clouds* are masses of mist in the upper air; they arise from the cooling of the higher layers of the atmosphere when fully charged with moisture, as mists and fogs are caused by chilling influences at the surface. Clouds are formed by the mixture of the moist air from the south with the cold currents from the north, just as the breath from our lungs becomes visible with mist in cold weather.

If, being on a mountain while it is raining, you enter the region of clouds, you will find yourself suddenly surrounded with thick masses of fog, and will perceive the fine droplets of the falling mists. But these little drops become larger as they fall; for, just as happens when any other cold body is plunged into moist air, the water is thrown down upon their surfaces, while they sink down through the lower warmer and vapour-charged layers of the atmosphere. The rain, therefore, which comes down to the earth is derived not only from the clouds floating in the higher atmosphere, which are only its first sources, but also from the lower regions between them and the earth, the whole of which contribute to its increase. A great difference may therefore be found between the amount of rain which falls on the top of a mountain, or even of a high tower, and that which is caught during the same time at the foot of either. Thus Dove tells us that the yearly rain-fall on the roof of the Royal Palace at Berlin is eighteen inches in depth, while that on the pavement of the Palace-Place amounts to twenty inches.

When the moist air in the upper regions is cooled down below the freezing-point, the water that it lets fall solidifies, and comes down as *Snow*. It is often remarked that it rains on the low-lying lands, while it is snowing on the mountains. In such case, the rain was withdrawn from the moist air as snow, which was melted during its fall through the lower and warmer regions. This thawing is often imperfect; it then rains and snows at once, or the snow-flakes, only softening, cling together, and come down as *Sleet*, which falls so often when the winter is passing into spring. Sleet is remarked in summer only on high mountains. It is probable that *Hail* consists of flakes of snow or sleet, which have been formed in the upper regions, and round which, as, in their fall, they passed through other mists separated from the moist air, the clear crust of ice was formed, which in almost all hailstones surrounds a core of white within. Hailstones of great size may, according to Dove's belief, be kept up in the air a long time by the whirlwinds which so often accompany storms of thunder and hail. Hail-storms are almost peculiar to summer and to the temperate zone. They occur at all hours of the day, but chiefly in the afternoon. Many places are much oftener visited by them than others, and, where a hail-storm occurs, it generally extends over but a small tract of country. Our knowledge of the laws of weather is as yet too narrow to enable us to account for this behaviour.

On the crests of very high mountains—for instance, on the Alps—single clouds are often seen to hang for days apparently motionless. They are, however, in ceaseless motion, just as is the moist air from which they are formed, as it sweeps over the cold and perhaps snow-capped peaks. With this air they travel on, and vanish again as soon as they are out of reach of the cooling influence; not, however, generally without leaving behind a part of their moisture as a fall of rain or snow. Thus the Alps are often, for many days together, shrouded in dense clouds, from which rain pours heavily every day, while over the warm valley of the Po, notwithstanding the constant south wind, the sky has never been clouded for a moment. In the same manner all high mountains are withdrawing the waters from the air even when it does not rain on the plains. Thus they are, in all parts of the world, the spots which form the chief points for the settlement of the moisture of the air, and are the main feeders of the rivers.

The wide plains of Northern India are, as you know, burning hot and dry during the summer. The currents of air rising up from the heated soil hinder the fall of wet from the air. The waters of the air, which are brought in unceasingly from the Indian Ocean by the south wind (the summer monsoon) cannot, therefore, be set down before they reach the Himalaya mountains, which, stretching for a length of nearly fourteen hundred miles almost due east and west, form the boundary of India. Here, however, the moisture is so thoroughly arrested, that the south wind having passed the mountain-range is almost completely dry before it reaches Inland Asia. Thus the Steppes of arid Asia form, for the most part, dry, barren wastes, with very hot summers and severe winters.

Much of the effect wrought by high mountains on the moisture of the air may be secured to the plains by careful attention to the forests. Forests are the natural gatherers of the moisture from the air. By the loosening which they give to the soil, by the plentiful undergrowth of herbage which thrives beneath their shelter, they hinder the rain water, even on sloping ground, from quickly running off. They everywhere check the currents of air, and thus retard the carrying off of the moisture by drying winds. Under their leafy shade, the heat of the summer is assuaged, and the few sun-rays that find their way to the soil, can lick up but little of the moisture for the warm currents to carry to the upper air. Again, because the water sucked up from the earth by the roots is breathed out again by the twigs and leaves as vapour, the air in the forests always remains moister and nearer to the dew-point than it does where the land is not wooded; while, therefore, the warm air is mounting up from the dry soil of the open country, the chilled and moister air must fall again from above upon the cooler surface of the woodland. Thus all the conditions necessary for the fall of moisture from the air meet in much greater force about the forests than over the open country.

When the south wind charged with vapour blows over dry ground heated by the sun, no fall of wet can easily take place; but rather the clouds that are ready formed, sinking down into the warmer layers of air below, are dissolved again and vanish. The parched warm soil drives the rain away from itself. But where the temperature is softened down by woods, and where the air, besides, is loaded with moisture by the constant evaporation, it will soon be overcharged by the falling clouds, and rain will follow. We are therefore right in commonly saying that the woods fetch down the rain, just as we are in saying that it is drawn to mountains and broad rivers. True it is, too, that the clouds cling to the forests as they do to the mountains, since the cool and moist air which floats over the woods, favours their formation; when, however, the resulting clouds, driven by the wind beyond the forest, reach the warm air rising up from a dry soil, they are again dissolved into invisible vapour.

On the other hand, we find that over single woodless islands in the sea, the sky remains cloudless, while all around thick clouds may be gathered, because the current, mounting up from the ground heated by the sun's rays, raises for a time the capacity for vapour in the higher layers of the air. The Canary Isles, when they were discovered, were clothed with thick forests, and overgrown with the richest verdure. Great part of these woods were destroyed and burnt by the first settlers; the result has been the lessening of their rains, and the dwindling away of their springs and brooks.

Thus the rooting up or even the mere thinning of forests always exerts a striking influence on the moisture of a country. Many districts, which, in former times were known for their rich fruitfulness, have lost, together with their forests, much of their flourishing condition, and have even been changed, in part, into desert. But you will also see that, by gradually planting trees, many regions of our earth, which have been hitherto waste and barren, may be rendered fit for tillage and the dwelling of man.

The air is in general moister over the sea than on the land; least so, however, in the region of the trade-winds. It there flows from colder to warmer regions, and so, its temperature gradually increasing as it advances, its power of taking up moisture is more and more enhanced. Within the region therefore of the trade-winds, the atmosphere is clearer, and rain scarcer. But between the north-east and south-east trades, in the belt of the calms, where the surface of the sea receives most warmth, and where, therefore, air fully charged with water is ever rising and spreading itself out, and thus is cooled down by degrees below the dew-point, it rains regularly every afternoon. The domain of the calms advances, as you know, and retreats with the sun; the rainy season sets in wherever it comes; and the dry season where the trade-wind prevails. Between the two periods there is a regular interchange, so that the former always answers to the highest, and the latter to the lowest, position of the sun. Thus it rains in the West Indies during the summer months, and is dry during the winter. In Brazil, however, the rainy season sets in at the same time as the dry season of the northern hemisphere; and conversely. A great part of this summer rain is driven by the west wind of the upper regions into inland Africa. But since the belt of the calms in the Atlantic always remains on the north side of the equator, it is chiefly in the parts of Africa lying in the north tropic zone that it rains in summer. The south-west of Africa, on the other hand, is remarkable for its extreme dryness. Over the parched soil, too, of Sahara, the atmosphere is seldom cooled down below the dew-point; there, then, it scarcely ever rains.

The lower trade, the dry wind, is met with, as you know, in the summer, even to the north of the tropic. In the region, then, of the tropics, it is dry in summer; but in autumn the upper trade, the rain-wind, comes down gradually lower and lower, and reaches the earth in winter in the latitude of the Canary Isles. On the borders, then, of the torrid zone the rainy season answers to the lowest position of the sun. On the north coast, too, of Africa, and in the south of Europe, we find the dry alternating pretty regularly with the wet season; but the latter becomes shorter as the latitude increases,—becomes curtailed into only a part of the summer,—because the south-west wind reaches the ground earlier the farther it goes north. In mid Europe, in Germany, there is no more of this regular setting in of a dry season. But there rainy weather may come at all times, wherever the north-east or the south-west wind may be prevalent. There it rains oftenest in autumn and in spring, but yet the hardest and most plentiful showers fall in the middle of summer.

The amount of rain that falls at different places has been compared by taking the depth to which the soil would be covered by all the rain received during the year. According to this, the mean amounts of rain at the places named below, are as follow :—

Names of Places.	Depth of Rain in Parisian Inches.	Rainy Days.
Bergen, in Norway	83	
Stockholm	19·2	
Petersburg	21·5	167
England West Coast	35	
England East Coast	24	
France Netherlands West Coasts	25	
Paris	21·3	160
Montpellier	30·4	85
Franecker	28·6	172
Göttingen	24·9	162
Berlin	19·6	171
Karlsruhe	25·5	174
Tübingen	24·0	110
Ratisbon	21·0	130
Augsburg	36·7	148
Tegernsee	43·0	170
Prague	15·4	109
Vienna	16·0	114
East of Europe	15	
Zürich	32·2	
Bern	43·3	
Geneva	28·5	103
Great St. Bernard	55·5	107
Milan	35·5	
Rome	29·3	120
Naples	35·0	
Palermo	20·8	
Funchal	27·3	
Cuba	86·0	
Guadaloupe	274·2	
Cayenne	109·9	
Maranhao	259·8	
Peru	0	
Persia	0	
Poonah (on table-land of India)	22·0	
Bombay	75·7	
Mahabuleshwar*	283·3	
Kandi (in Ceylon)	68·9	

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* Mahabuleshwar, on the western slope of the Ghauts, not far from Bombay, is, so far as we know, the spot at which, of all the earth, the most rain falls; and nearly the whole of this enormous amount of rain, almost twenty-four feet in depth, comes down in the months of June, July, August and September.

LETTER XVI.

THE ELECTRICITY OF THE AIR, AND LIGHTNING.

I MUST not conclude my account of the causes of the fall of wet from the air, and of the conditions which bring it on, without calling your attention to the phenomena of thunder and lightning which so often forerun and accompany heavy floods of rain.

Lightning is, as every one now knows, an electrical action on a vast scale, but the same in kind as that which we obtain artificially by the electrical machine and the Leyden-jar, and which we consider as the work of a peculiar power of nature, of *Electricity*. You are, of course, so far generally acquainted with electricity, as to be aware that it is a very subtle force, endowed with peculiar powers;—that it is sometimes considered as a fluid which, like the air, strives for boundless expansion, and which therefore has very different degrees of density according to the conditions in which it is placed;—that it is more or less checked, in its endeavours to spread itself, by many substances, which are called *non-conductors* —for instance, by the air; while there are others, such as water, metals, moist earth, &c., which readily carry it, and are therefore called *conductors.* Through these latter it passes easily, and always gathers itself upon their surfaces, if, by being surrounded by non-conducting matters, it is hindered from going farther. You must remember, too, that, according to the views of many naturalists, there are supposed to be two electric fluids, the *positive* and the *negative,* each of which, indeed, taken by itself, seems to have exactly the same properties as the other; but that there is this great difference between them, that, while bodies charged with the same sort of electricity—for instance, with the positive—drive each other away, two that are charged with the different electricities, that is, the one with the positive, the other with the negative, are always drawn together.

A body is said to be electrised when it is charged with one or the other of the electricities. All bodies commonly, that is, when not in the electric state, contain the two electricities equally, each of which therefore exerts, on things around, its own peculiar action, which, being neutralised by the other, is not to be perceived. If, however, an electrised body is placed near one that is excited, that electricity in the latter, which is the same as that of the former, is driven away from the neighbouring electrised body, and the contrary electricity is drawn towards it; so that by this influence the two are sundered, and can now work each by itself.

The *Electric Spark* is an appearance presented at the instant when two unlike mutually attracting electricities pass over to each other through a layer of air that had been between them, and thus join, to return to the common state of insensible electricity, of which I have just spoken.

Benjamin Franklin was the first to show with certainty that the electrical discharge of a thunder-cloud, *the flash* of lightning, differed from the spark obtained from the electrical machine only in the amount of force put forth. He remarked of it, that the zigzag of the flash has the closest resemblance to the shape of a strong electric spark discharged through a good distance;—that the flash strikes most often on high objects over-topping others near them, such as the peaks of mountains, the masts of ships, lofty trees, towers, &c., just as the electric spark most readily passes over to the most jutting parts of neighbouring bodies;—that the flash chiefly seeks out things that are good carriers of electricity, such as metals, water, &c., avoiding non-conductors;—and lastly that, just like any strong electric spark, it kindles substances that will burn, fuses such as will melt, rends such as can be torn or split, and destroys animal life.

But Franklin showed, too, by direct experiment, that thunder-clouds behave exactly as conductors, which might be charged with electricity, and insulated by the surrounding air—that is, cut off from any electric communication with the earth. He sent up a kite furnished with some wire points, while a thunder-cloud was forming. Thus, by means of the string, which, by being moistened, became a carrier for the electricity, or by means of a fine metal wire, which ran down from the points, and was twisted into the string, he succeeded in drawing down electricity from the cloud, and in performing all the experiments for which we usually resort to the aid of an electrical machine. These experiments were afterwards repeated and verified at many places.

By this simple means—the electric kite—it has been proved, that not only thunder-clouds, but all clouds, are electrical, and that even the dry air at all times contains electricity in great amount but of very slight density. Many processes that are going on upon the earth are possibly aiding to maintain this condition, by generating electricity, and giving it off to the air; such as the rubbing of the wind, and of evaporated water against solid bodies, the burning of fuel, &c. What, however, is to be considered as the main source of the electricity of the air, is as yet by no means clear.

If clouds are formed, which, being water gathered together in the atmosphere, can carry electricity, and if they are surrounded by non-conducting air, the electricity, which was already present in their neighbourhood, gradually collects upon their surfaces, just as takes place with any other insulated conductor, to which electricity is imparted. These charges, however, are generally drawn off to the earth by rain or snow, without any very striking effect. But, if the mass of clouds is very large, and the gathering of the water within them takes place very quickly and plentifully, then their inner body becomes in a short time a most excellent conductor, and may suddenly send up to the surface of the cloud electricity enough in amount, and condensed to such a degree, that a powerful discharge must follow—a flashing of the spark to another cloud, or, perhaps, to the surface of the earth, through the layer of air between—before the charge can be gradually let off by the fall of rain.

The lightning is commonly accompanied by a loud noise,—the *Thunder*. It is the result of the shock, which is occasioned by the flash in bursting through the air, and is owing to the same cause as is the snap of the smallest electric spark. The long resounding roll of the thunder arises from the echo of the first single crash thrown back from hills and heights, and from the clouds themselves.

Every sound requires, as you know, a certain time to travel from the place at which it starts, to any distance at which it may be heard. The speed with which sound is sent through the air is about one thousand one hundred and forty-two feet in a second. Light coming from any source on the earth, and, therefore, also from lightning, if it reaches the eye at all, is perceived at the very moment at which it issues. The number of seconds, therefore, that pass between the instant at which the light of the flash reaches the eye, and that at which the sound reaches the ear, multiplied by 1142, will give the distance in feet between the place where the observer stood and the spot where the flash occurred.

Every thunder-cloud may be compared, as I have already mentioned, to a conductor charged with electricity, and insulated by the surrounding air. If an electrised conductor be insulated and surrounded with various substances, good conductors and bad, the natural electrical condition of all of them, without exception, will be disturbed, the electricity, like to that of the conductor, will be driven from it, and the unlike drawn towards the conductor. The tension thus given to the electricity, gathered up and struggling against the non-conductor that keeps it back—against the air,—is greater the nearer the conductor is approached by the bodies around it. This sundering, however, of the two electricities, which in their common state are combined, takes place most quickly and most perfectly in those of the surrounding bodies which have the best conducting power, and especially in those which are the most intimately connected by conductors with the earth, the grand carrier and universal holder of electricity. The electric spark can, it is true, start across to any of the bodies around the insulated conductor; but will most surely strike that one which is nearest to it, and at the same time the fittest to carry off the electricity to the ground.

These conditions belong as truly to the thunder-cloud as to any other insulated conductor. Whenever a heavily-charged cloud passes over the surface of the earth, the natural electrical state of all the bodies under the cloud must be deranged. The contrary electricity attracted by that of the cloud, and thus drawn up to the highest jutting points on the earth-surface, is gradually gathered together as the cloud approaches, and again gradually retires as the cloud passes off. A person exposed to this influence may not feel anything of it; but if the cloud should, while over him, suddenly discharge itself in an entirely different direction, whereupon its action on the earth must suddenly cease, he may, without being himself touched by the flash, suffer a very severe and even dangerous shock, from the mere return to the earth of the electricity, which had been drawn into his body,—by the *back-stroke.*

The more electricity a thunder-cloud contains, the nearer it approaches the earth, the moister, and the more conductive the layer of air between them, the more conductive the bodies on the earth may be, and the more perfect their connection with great masses of wet ground, or with running water,—so much the more easily will the electricity of the same kind with that of the cloud be driven away downwards, and the contrary electricity drawn up and gathered together on the surface of bodies; and, therefore, so much the more likely is the occurrence of an electrical discharge.

Now, in this discharge, in the passage of the flash, both the electricities play their part alike; both that which is gathered in the cloud, and that which is opposed to it on the surface of the earth; and you have just as much reason for saying that the lightning flashes up from the earth to the cloud as that the flash strikes down from the cloud to the earth. In fact, the two pass over to each other; and where one of them is wanting, where, for instance, a want of conducting power in the bodies on the earth hinders the complete separation of their electricities, a discharge need not be feared.

If, on the other hand, there is placed among several bodies on the earth, one which is a far better conductor than any other in its neighbourhood, if, besides, it towers up above them, and yet is in excellent conducting connection with the moist ground, the flash, when it strikes, will most likely choose it out before all other objects.

By the term *lightning-conductor*, we mean such a conductor as we may be certain will present itself as a channel before any other object near it, for the passage to each other of the electricities of the earth and cloud. The conditions which are especially requisite in a lightning-rod, are at once evident from a due consideration of the known properties of electricity. The metals are the fittest materials for the purpose, since they surpass, beyond all comparison, every other substance in conducting power. Copper, again, would be chosen as the best conductor among metals; iron, however, is commonly preferred on account of its cheapness.

This metallic conductor must now be placed so as to jut up above the highest point of the building to be protected, and must run down in unbroken metallic connection to the moist earth or to running water, presenting to these the greatest possible number of points of contact, so as to favour the escape of the electricity. Throughout its whole length, too, it must be thick enough to offer less resistance than any other body near it, to the passage of the greatest possible quantity of electricity that can come from a thunder-cloud, during its course through the metal to the earth. The flash often strikes single trees that stand by themselves, because, rising, as they do, to a considerable height, and sending some of their roots deep down, while others branch out in every direction through the soil, they form true lightning conductors. However, they possess but a low degree of conducting power. Hence, to take shelter under them is very dangerous; for the electricity, not being able to pass through them very swiftly, starts across in part to other better conductors, such as men and beasts, if any such be at hand, and through them finds its way to the ground.

Water, again, is a worse conductor than living animals. The danger, therefore, of such being struck by lightning, is always increased rather than lessened by their being in the neighbourhood of water.

The case is altogether different with metallic conductors of sufficient thickness. The lightning will not leave them, even when the metal rod lies directly upon wood or stone, not even if it should pass through water, not even if one should grasp it with the hand, since no other body can afford a quicker passage to the electricity than does the metal; only the chance of some fault in the metallic connexion of the conductor, or of its failing to reach deep enough into the moist soil, may make it wise to keep at some distance from the lightning-rod.

If, however, a lightning conductor does not possess the qualities which I have mentioned; if, for instance, it is not thick enough, there is then not only the danger of its being heated, and even melted, but, by reason of its want of conducting power, a part of the electricity may be allowed to dart off to other neighbouring bodies. Now a conductor, that has been put up in this faulty state, or that has got out of order, can certainly not give entire security. It would be wrong, however, to suppose that it increases the danger, by drawing it down, without being able to ward it off.

A faulty conductor ceases to afford security, just because it does not strive to draw down the electricity from the clouds much more powerfully than do the other objects near it. It cannot therefore in any case invite the danger more than commonly do good conductors, such as, for instance, chimneys with their lining of soot, and with the moist vapours rising within them, iron stoves, water-pipes, metal roofs, and generally great masses of metal, which are put up in buildings so often, and without scruple.

THE END.

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